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POST-TRAUMATIC OSTEOPENIA

A QUANTITATIVE STUDY OF THE BONE MINERAL MASS IN THE FEMUR FOLLOWING FRACTURE OF THE TIBIA IN MAN USING AMERICIUM 241 AS A PHOTON SOURCE.

BO E R NILSSON

MUNKSGAARD COPENHAGEN 1966

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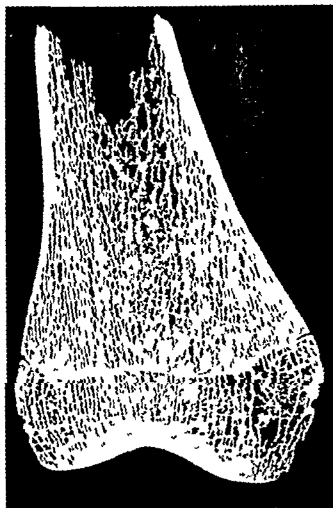


Fig. 1
Section of the distal end of the femur with the epiphyseal line clearly visible (from SPALTEHOLZ 1932). Note the proportions of trabecular and cortical bone

II MATERIAL

A PROBANDS

1 *Selection of Probands*

The probands 41 males and 49 female were selected from a population more than 500 ca es of fracture of the haft of the tibia treated in the Department of Orthopaedic Surgery The General Ho pital of Malmö the years 1949 to 1964 To qualify as a proband the individual case to fulfill the following criteria (1) age at injury 16 years or over no additional injury di ea e or urgical procedure to the lower extrem ies previous to at the time of or following the fracture (3) no osteomyelitis urgical procedure intended to promote union except for primary reatment of the fracture and removal of materials u ed for internal ixation (4) no deformity of the lower extremities including difference in ze The latter parameter was evaluated from the difference in width of he condyles which was not allowed to exceed 10 mm By the last criterion only three cases were excluded

Only part of the available cases were u ed as probands in this study for young females where no substantial increa e of the ample size could have been attained Attempts were made to cover adult age groups follow up time evenly With the e restrictions the probands were cted at random

2 *Type of Injury*

Definitions and clinical evaluation follow tho e outlined by EDWARDS 1965) in a study of the clinical material from which mo t of the proband ere drawn

(a) *Type of Fracture*

Transverse Fractures All fractures in which the fracture line formed an angle of 45°—90 with the long axis of the shaft and all comminuted fractures that is those with one or more intermediate fragments involving at least half of the bone diameter These fractures were generally the result of direct severe violence such as traffic accidents and crush injuries

Longitudinal Fractures The group includes longitudinal and long oblique fractures which usually were cau ed by le s severe and indirect trauma

Comminuted Fractures Although these injuries are included in the grou

of transverse fractures they were in this study also recorded separately since they regardless of the trauma represent a more extensive injury to the bone tissue

(b) *Skin Injuries*

Open Fractures Injuries where a wound communicated with the fracture

Closed Fractures All other fractures

(c) *Location of Fracture*

Proximal Fractures Fractures of the proximal third of the tibia

Distal Fractures Fractures of the two distal third of the tibia

3 *Immobilization*

EDWARDS and NILSSON (1965) found that the healing of fractures of the shaft of the tibia is normally distributed in relation to the logarithm of time As healing time can be set essentially equal to the time of plaster immobilization this concept was applied to the probands The results of a graphical probit analysis using the logarithm of plaster immobilization time is shown in Fig 2 and Table 1 No major differences were found between the sexes either in the time of plaster immobilization of 50 % of the cases or the time of plaster immobilization of 95 % of the cases For further information with regard to the method of calculation of these figures and for comparison to the main material the reader is referred to EDWARDS and NILSSON (1965)

4 *Disability*

The time period from the accident until normal activities were resumed was defined as the time of disability and was possible to establish in all but three of the probands Again a primarily skewed distribution was normalized by giving time a logarithmic transformation The result of a graphical probit analysis are shown in Figure 3 and Table 2 The validity of this approach has only been tested in the probands and more general conclusions should not be made

5 *Final Status*

The final status of these cases was evaluated according to EDWARDS (1965) *Non good final status* in this study refers to conditions other than good according to EDWARDS criteria and includes cases where knee or ankle motion was decreased cases with pain and cases where to any extent the capacity for heavy work or sports activities was limited

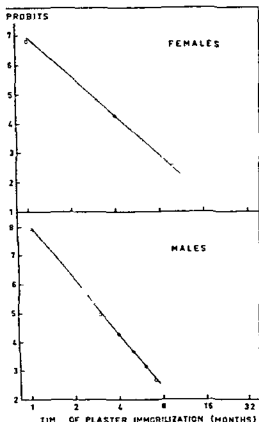


Fig 2
A graphical probit analysis of fracture healing in relation to time In both sexes the distributions are close to normal

Table 1

Time of plaster immobilization (months) required for healing of

	50 % of the probands	95 % of the probands
Females	2 9	6 5
Males	3 5	5 8

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B ADDITIONAL CASES

1 *Subjects with Complicating Factors*

Ten additional subjects were measured which did not qualify as probands cording to criteria (2) and (3) (Chapter II A 1) These cases were icated by factors such as additional injury osteomyelitis or secondary irgical treatment of the fracture

2 *Subjects with Fracture in Childhood*

Sixteen subjects were measured which did not qualify as proband ording to criterion (1) (Chapter II A 1) Two of these were children easured within two months of the fracture Fourteen were measured al years after the fracture at a time when their knee size was compar ble to adults

3 *Subjects without Fracture*

The mineral mass of the distal end of both femora was evaluated in y one females over age forty with clinically normal knees and without ractures or other injuries to the lower extremities These data which rimarily were obtained for a study by ALFFRAM et al (1966) were used in study mainly for the analysis of the error

COMMENT

Most cases involved in this study have been described in detail by DWARDS (1965) In the Appendix data pertinent to the present study are including references to EDWARDS

III METHOD

A SELECTION OF METHOD

The measuring device consisted of a gamma emitting radionuclide a collimator system and a scintillation detector The mineral content of the cancellous bone in the distal end of the femur was evaluated from the attenuation of a collimated photon beam penetrating the epicondylar area (Fig 4) The method was chosen on the following grounds

(a) Mainly trabecular bone would be measured (Fig 1)

(b) The simplest way to accomplish a monochromatic photon flux is by the use of a gamma emitting radionuclide This method simplifies the data processing and permits, with certain approximations the estimation of the actual mineral content of the measured bone tissue

(c) Preliminary experiments made it clear that the integration of a single step scan across the distal end of the femur gave less precision and presumably included more cortical bone than a single wide beam passing through the epicondylar area

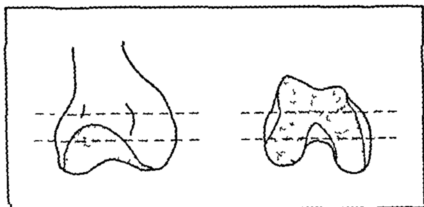


Fig 4
The pathway of the beam through the distal end of the femur

At first the radionuclide Iodine 125 (gamma 27 3 keV halflife 60 d) was tested It was found to have an energy too low to permit measureable transmission through the distal end of the femur using sources of a reasonable activity Due to substantial differences in the attenuation properties of fat as compared to other constituents of the soft tissue, systematic changes in composition may introduce substantial systematic errors These difficulties are largely overcome if photons of a somewhat higher energy

uch as the gamma radiation from Americium 241 (gamma 26 9 keV and 9 6 keV Fig 6) are used The latter radionuclide also has the advantage f a long half life (475 years) The difference in attenuation properties of bone mineral and soft ti ue at this level of energy is till sufficient to permit a reasonably accurate in vivo evaluation of bone mineral content OMNELL, 1957)

B EQUIPMENT

1 *Source*

About 0 7 Curie of Americium 241 in the form of Americium Oxide[1] of high pecific activity was u ed as a ource of radiation The ource material was transferred into a brass container of ufficient dimensions to provide virtually complete shielding and with the pos ibility of attaching various collimators (Fig 5)

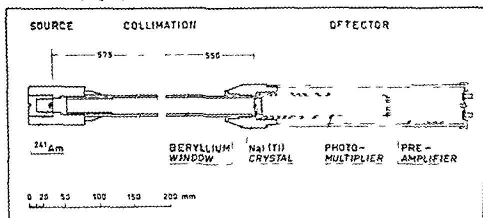


Fig 5
The measuring device

2 *Detector*

A system for detection of the transmitted radiation was *designed according* to Fig 5 Attention was paid to the neces ity of a low noi e level The following pieces of equipment were used

Crystal NaI (TI) 1/2 × 1 ' with Beryllium window
Photomultiplier with preamplifier
Pul e amplifier—high voltage supply unit
Pulse analyzer (EKCO N 102)
Scaler (EKCO N 530)

[1] National Laboratorie Oak Ridge Tenn
[2] De igned and built by Leopold Arlo Dept of Biochem try Univer ity of Lu d

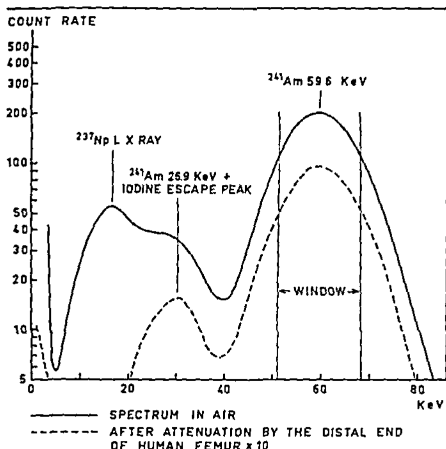


Fig 6

Spectrum of Americium 241 unobstructed radiation and radiation attenuated by the distal end of the human femur By means of a pulse height analyzer the radiation was discriminated so that only photons within the range of the window was recorded by the scaler

3 *Collimation*

Tube collimators were attached to the source and the detector The length (total 1125 mm) and diameter (18 mm) of the collimators was empirically designed to minimize the influence of scatter and to include a reasonable amount of bone tissue in the measurement

C. PROPERTIES OF THF MI ASURI\G DE\ICF

In Fig 6 the spectrum derived from the Americium 241 ource u ing the letection sy tem de cribed above i hown Source and detector were ositioned and collimated in the same way as when patient were mea ured ig 6 al o hows the spectrum obtained after attenuation of the radiation y the di tal end of the femur of a human ubject The low energy radiation mitted from the ource (26 9 keV gamma rays and Neptunium 237 -X rays) was attenuated to a level where it es entially did not exceed ackground Under the experimental condition the distal end of the femur ttenuated the 59 6 keV gamma radiation by a factor of up to twenty

With the window of the pul e height analyzer et on the 59 6 keV photo eak (Fig 6) in thi tudy two advantage were achieved (a) background ecame negligible and (b) monochromatic propertie were obtained i.e he tran mitted inten ity wa a monoexponential function of the thicknes f the attenuating matter (Gilson et al 1965)

This property of the mea uring device wa vi ualized by the attenuation n Aluminum plates (Fig 7) Th mea urement wa undertaken repeatedly uring the study a a check of the sy tem

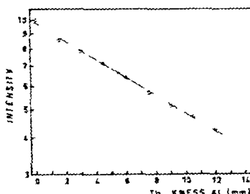


Fig 7

The Americium 241 radiation attenu ated by a series of 1 5 mm Aluminum plates inserted between the colli mators

D PROCEDURE

With the patient itting and the knee joint in about 90 flexion the apertures of the collimators were fitted to the epicondylar areas of the di tal end of the femur *located by palpation (Fig 8)* *Without changing the* di tance between the collimator apertures the knee was repo itioned ten imes and the time for 3000 count recorded each time Again in the same pace the contralateral knee wa po itioned in the same way and ten dditional mea urements were made Finally a water filled pla tic cu hion



Fig 8
The position of the subject

which could be expanded to fill the entire space between the collimator apertures was introduced and the time for 30 000 counts was recorded The entire procedure was then repeated including the adjustment of the space between the collimators

Using an anthropometric caliper the width of the condyles across the measured area was recorded Pressure was put on the caliper in order to minimize the importance of variations in thickness of the subcutaneous fat layer in this area The remaining contribution from interposed skin to the measure of the condyle width was accounted for by subtracting 0 6 cm the figure found to be the average and a fairly constant one in measurements on cadaver

All the measurements of subjects involved in this study were carried out by the same technician

F CALCULATIONS

From the obtained measurements the mineral content of the distal end of the femur was calculated according to Lamberts law

$$I = I_0 \quad e^{-\mu d}$$

$_o$	Intensity of the unobstructed radiation
H_2O	Intensity after attenuation by water
$_{min + org}$	Intensity after attenuation by the subject
$_{org}$	Linear attenuation coefficient of soft tissue and organic component of bone (l/cm)
$_{H_2O}$	Linear attenuation coefficient of water (l/cm)
$_{min}$	Linear attenuation coefficient of bone mineral (l/cm)
	Total thickness of the subject (cm)
$_{min}$	Thickness of the mineral in the pathway of the beam (cm)

.amberts law *applied to measurements of the specimen may* be expressed

$$I_{min + org} = I_o \quad e^{-\mu_{org}(d - d_{min})} \quad e^{-\mu_{min} d_{min}} \qquad (1)$$

nd to the measurement of the water cushion

$$I_{H_2O} = I_o \quad e^{-\mu_{H_2O} d} \qquad (2)$$

f the *linear attenuation coefficients* are assumed to be equal for water nd soft tissue the former may be substituted for the latter in (I) and the quations may be solved for d_{min}

$$d_{min} = \ln \frac{I_{H_2O}}{I_{min + org}} \times \frac{1}{\mu_{min} - \mu_{org}} \qquad (3)$$

Tabulated values which represent approximations were introduced for nass attenuation coefficients and densities of bone mineral and soft tissue ncluding the organic constituents of bone (OMNELL 1957 GRODSTEIN 1957 McGINNIES 1959)



Fig 8
The position of the subject

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E CALCULATIONS

From the obtained measurements the mineral content of the distal end of the femur was calculated according to Lamberts law

$$I = I_0 \; e^{-\mu d}$$

In this study it ha been nece ary to relate the mineral content of the actured limb to the mineral content of the control limb a uming that he e two value originally were equal The as umption introduce a good eal of the error involved in thi study and further attempt to decre e he methodological error would probably have yielded but little additional iformation

I DATA REPRESENTATION AND STATISTICAL ANALYSIS[1]

For comparison of classe such as males and females open and closed actures etc covariance analysis was applied to the relation hip of the ineral content of the control and the fracture limb the value of the control mb was taken as the covariant factor Thus the mineral content of the actured ide for any given mineral content of the control side was com ared between the clas es (SNEDECOR) Male and female proband were reated separately as well as pooled

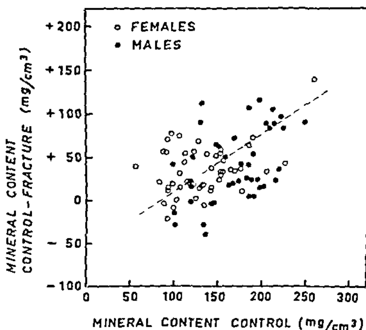


Fig 12

he relationsh p of the mineral content of the uninjured limb and the lo s of l one (control racture) There is a significant po itive correlation in l oth sexes as well as f r the pooled data

[1] The statistical analy is was uperv ed by Melvin S Schwartz M D Divi ion f Biometric Cornell University Medical College New York City

The difference in mineral content between the two limbs may be used as a measure of post traumatic osteopenia In Fig 12 this difference is plotted against the mineral content of the control limb A significant ($0.01 > P > 0.001$) positive correlation was found Other factors disregarded this implies that individuals with a greater mineral content are apt to lose more of this mineral This fact may be corrected for by using the fractional loss that is the difference expressed as a fraction of the control side

The mineral content of the fractured limb without regard to its relationship to the control limb may also be used as a measure of post traumatic osteopenia

These three values plus the value of the mineral content of the uninjured side the age at the accident the age at the follow up the follow up time the time of immobilization and disability and the width of the condyles (measured with caliper) were all correlated In addition these parameters were examined for partial correlation in order to study the possible influence of interaction among these different variables (SNEDECOR) Whenever the three methods of representation of the degree of post traumatic osteopenia gave non consistent results this will be commented on The results of significant tests will be given as probability levels obtained from standard statistical tables (FISHER and YATES 1963)

IV RESULTS

MINERAL CONTENT OF THE DISTAL END OF THE FEMUR OF THE NON FRACTURED LEG

1 *Quantification*

The mineral content of the measured area of the non fractured control g with the approximations stated (Chapter III E) was found to be 49 ± 43 mg[1] bone mineral per cc of bone

COMMENT

This finding is in agreement with *in vitro* measurements of the ash content f trabecular bone from various parts of the skeleton ARNOLD (1960) and IUELLER et al (1966) found the ash content of specimens of trabecular bone rom vertebral body and ileum to vary between 100 and 200 mg per cc OSE (1960) and MAYO (1961) found the same distribution in *in vivo* tudies of the mineral content of the distal end of the femur and the alcaneum respectively

2 *Influence of Sex*

The mineral content of the distal end of the femur in males (167 ± 39 ig per cc[1]) was significantly higher ($P < 0\ 001$) than in females (134 ± 39 ig per cc[1])

COMMENT

Similar differences between the sexes in various parts of the skeleton iave been demonstrated by other investigators (BROMAN et al 1958 'IRTAMA et al 1960 MEEMA 1963 MEEMA and MEEMA 1963 SAVILLE 1965)

3 *Influence of Age*

The age regressions of the mineral content of the non fractured side are hown in Fig 13 for probands and those of the additional cases with racture who at the time of follow up had reached the age of sixteen For males there was a significant negative correlation ($0\ 02 > P > 0\ 01$) or females the negative correlation was suggestive ($0\ 1 > P > 0\ 05$)

[1] Average ± standard deviation

Fig 13

The relationship of age and mineral content in the uninjured limb

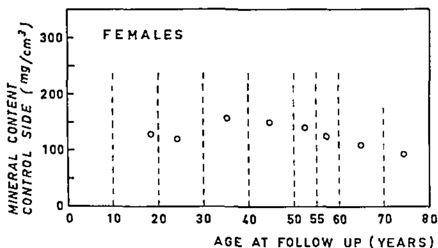


Fig 14

The relationship of average age and average mineral content in the uninjured limb in consecutive age groups in females

COMMENT

In Fig 14 the average mineral content i plotted again t the average e within con ecutive age groups in female From the general pattern can be ob erved that the mineral content of the di tal end of the femur mains unchanged or po sibly even increa es lightly until the fifth decade f life when it starts to decrea e A similar pattern ha previou ly been ound by several inve tigators (BARNETT and NORDIN 1960 GARN et al 963 MEEMA 1963 MEEMA and MEEMA 1963 BAYLINK et al 1964 MEEMA t al 1965 SAVILLE 1965 SMITH and FRAME 1965) The catter of the data i females appears to be le during the ixth decade of life than during ther age groups covered by this tudy

4 *Influence of Trauma*

The mineral content of the di tal end of the femur in the control limb f female probands over age forty was compared to that of the non actured ca es (Chapter II B 3) the latter group having approximately he same age range There was no difference between the e group

In a comparison of probands who had sustained their fracture as a re ult f a moderate and indirect trauma (longitudinal fracture) to tho e who ad suffered a direct and more severe trauma (tran ver e fractures) no ignificant difference could be demon trated

COMMENT

Contralateral loss of mineral has been ob erved in ca es of trauma to the ower limbs (SCHEIBE 1956) In female probands over forty years of age uch a contralateral involvement was not frequent enough to decrea e ignificantly the average den ity of the group below that of a non fractured opulation

VOSE and LOCKWOOD (1965) found that fracture of the neck of the femur as more common in individuals with a low bone den ity However in the re ent tudy probands with a hi tory of moderate trauma did not differ n their mineral content from those with a evere trauma and endogenous actors such as decreased bone mass are probably less important for the tiology of fracture of the shaft of the tibia

B POST TRAUMATIC OSTEOPENIA

1 *Quantification*

The mineral content of the distal end of the femur was in most of the robands lower in the fractured side as compared to the non fractured

FEMALES

MALES

MINERAL CONTENT CONTROL SIDE (mg/cm³)

AGE AT FOLLOW UP (YEARS)

Fig 13
The relation hip of age and mineral content in the uninjured liml

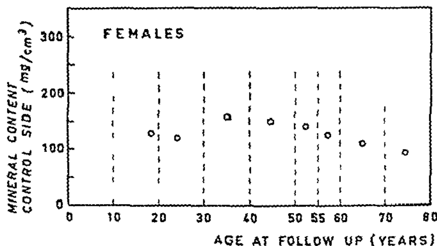


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B POST TRAUMATIC OSTEOPENIA

1 *Quantification*

The mineral content of the distal end of the femur was in most of the roband lower in the fractured side as compared to the non fractured

The difference was 38 ± 35 mg per cc of bone[1] or expressed as a percentage of the non fractured side approximately 25 % The difference was related to the mineral content of the non fractured side, so that a high mineral content of the latter was associated with a greater loss of mineral (Fig 12)

2 *Influence of Fracture Type*

There was no significant difference in the degree of post traumatic osteopenia between the transverse and the longitudinal types of fracture nor was there any significant difference between open and closed fractures between comminuted and non comminuted fractures between proximal and distal fractures or between the various combinations of these groups in either sex

When the probands were compared to cases with complicating factors such as osteomyelitis secondary surgery or additional injuries (Chapter II, B 1) the latter group was found to have a significantly higher degree of post traumatic osteopenia ($0.05 > P > 0.01$) The average loss in this group was 40 %

3 *Influence of Immobilization and Disability*

The probability levels for significance tests applied to the relationship between post traumatic osteopenia immobilization and time of disability are shown in Table 4 The overall finding was that in males and possibly in females post traumatic osteopenia was more pronounced in cases with a longer time period of plaster immobilization or with a longer time period of disability following the injury (Fig 15 and 16)

Comment

As previously shown, the time of immobilization and disability were both skewed distributions The use of correlation coefficient implies the assumption that the data are more or less normally distributed Therefore the correlations were repeated using the logarithm of plaster time and time of disability This operation did not to any marked degree change the outcome of the correlations In Table 4 it should be noted that even if a 5 % confidence level is not attained in several of the correlations the slope

[1] Average ± standard deviation

Table 4

	Male		Females		
	P of correlation	Slope sign	P of correlation	Slope sign	
Plaster time vs mineral content fracture side	0.05 P 0.02	—	P 0.1	—	
Log plaster time vs mineral content fracture side	0.05 P > 0.02		P 0.1	—	
Plaster time vs mineral loss (control—fracture)	P > 0.1	+	P 0.1	+	
Log plaster time vs mineral loss	P 0.1	+	0.1 P 0.05	+	
Plaster time vs fractional mineral loss (control fracture/control)	0.05 P > 0.02	+	P 0.1	+	(Fig. 15)
Log plaster time vs fractional mineral loss	0.1 > P > 0.05	+	P 0.1	+	
Disability time vs mineral content injured side	0.02 > P 0.01		P 0.1		
Log disability time vs mineral content injured side	0.05 > P 0.02		P 0.1		
Disability time vs mineral loss (control—fracture)	0.1 P 0.05	+	P 0.1		
Log disability time vs mineral loss	0.1 P > 0.05	+	P 0.1	+	
Disability time vs *fractional mineral* loss (control—fracture/control)	0.0 > P 0.01	+	P 0.1	+	(Fig. 16)
Log disability time vs fractional mineral loss	0.05 P > 0.02	+	P 0.1		
Disability time vs plaster time	0.01 > P 0.001	+	0.01 P 0.001		

4 *Influence of Final Status*

There was no difference between proband with good and probands with 'non good final status as regards the degree of post traumatic osteopenia

5 *Influence of Age and Sex*

There was no significant correlation between the age at the time of the accident and the degree of post traumatic o teopenia nor was there any significant difference between the sexes

Comment

The difference in the mineral content between the fracture and the control side was greater in subjects with a high mineral content in the uninjured leg Although the average difference between the limb was greater in males this may be explained by their originally greater mineral content and the difference for any given den ity of the non fractured side was not significantly greater than for the females

In the non probands who sustained their fractures before age sixteen there was no significant difference between the fracture and the control limb Thi finding which will be di cu ed later may reflect a high ability to restore the lo t bone In two children (Cases 115 and 116) where the mea urements were performed within two months of the injury, there was a substantial lo s of bone

C RESTORATION OF BONE MINERAL MASS IN POST TRAUMATIC OSTEOPENIA

1 *Probands*

In *males* the difference between the fracture and the control side was found to decrea e significantly ($P < 0\ 001$) with time elapsed after the injury (Fig 17) In *females* there was no significant change with time so that the difference between the fracture and the control leg was approximat ely the same in ca es observed during the first years following the accident and in tho e ob erved ten to fifteen years after the injury (Fig 18) If only males over 50 years of age were included the correlation remained significant ($0\ 01 > P > 0\ 001$) whilst there was no correlation in females either before or after the age of 50

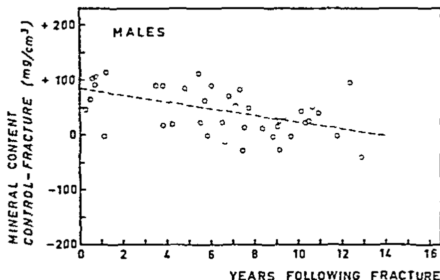


Fig 1

'he relation hip of time after fracture an l po-t traumatic osteopenia *in males* The .ifference between the limbs decrea es at l a t during ix or seven years after that time there is n notical le change

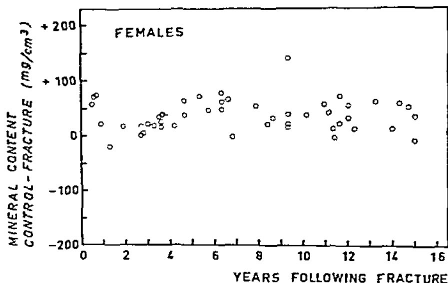


Fig 18

The r lation hip of time after fracture and post traumatic o-teopenia *in females* There ι no noti eable change in the degree of post traumatic osteopenia during the time period covered in this tudy

Comment

In males there was no evidence of relationship between the mineral content of the control side and the follow up time but there was a significant positive correlation between the fracture side and the follow up time ($0.01 > P > 0.001$) Therefore it must be assumed that there is a true increase in the mineral mass of the distal end of the femur in males with time following the fracture

2 *Children*

As a group, individuals who sustained their fracture before the age of sixteen had no significant post traumatic osteopenia When the difference in mineral content between the fracture and the control side was plotted against the age at accident there was a significant positive correlation ($0.01 > P > 0.001$) (Fig 19) There was no significant correlation between the time elapsed after the injury or the age at follow up and the difference in mineral mass There was a significant correlation of the mineral content of the fracture side and the age at accident ($P < 0.001$)

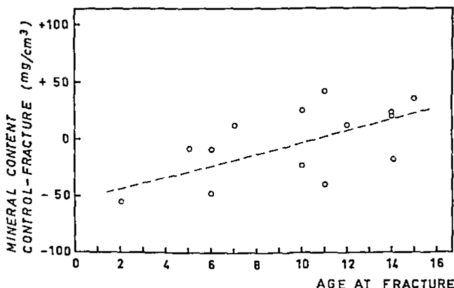


Fig 19

The relationship of age at fracture and post traumatic osteopenia in individuals who had sustained their fracture in childhood The mineral content was often found to be greater in the fracture side as compared to the control Individuals who had sustained their fractures as teenager did not differ from adults in this respect

Comment

This finding may be due to an increased ability in young children to compensate or even over compensate for lost bone mineral. The restoration probably takes place within the first few years following the injury. Although the limited data does not allow for an accurate evaluation of the time sequence, it may be pointed out that the zero intercept (about eleven years of age) may indicate the average age after which the ability to restore bone is lost. The loss of bone mineral in teenagers was not significantly less than in adults.

D. INFLUENCE OF INTERACTION

The possibility of interaction among the many variables was examined by means of partial correlation computation. There was no evidence that any of the positive findings in this study were significantly elevated by such interactions, nor did any of the non significant correlations become significant when interaction was accounted for.

Comment

In males there was no evidence of relationship between the mineral content of the control side and the follow up time but there was a significant positive correlation between the fracture side and the follow up time ($0.01 > P > 0.001$). Therefore it must be assumed that there is a true increase in the mineral mass of the distal end of the femur in males with time following the fracture.

2. *Children*

As a group individuals who sustained their fracture before the age of sixteen had no significant post traumatic osteopenia. When the difference in mineral content between the fracture and the control side was plotted against the age at accident there was a significant positive correlation ($0.01 > P > 0.001$) (Fig. 19). There was no significant correlation between the time elapsed after the injury or the age at follow up and the difference in mineral mass. There was a significant correlation of the mineral content of the fracture side and the age at accident (*$P < 0.001$*).

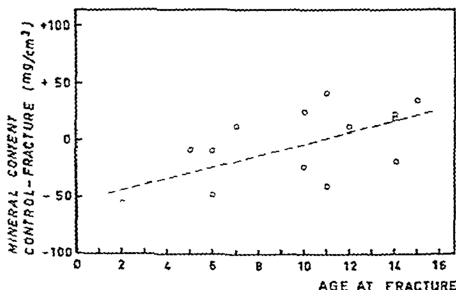


Fig. 19

The relationship of age at fracture and post traumatic osteopenia in individuals who had sustained their fracture in childhood. The mineral content was often found to be greater in the fracture side as compared to the control. Individuals who had sustained their fractures [illegible] from adults in this respect.

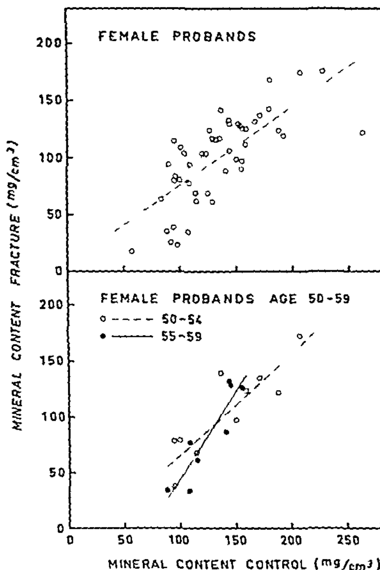


Fig. 20

The regression of the mineral content of the control and the fracture limb in two age groups in *females*. In the total number of female probands the slope is < 1. In the age group 50–54 the slope is approximately 1 and not significantly different from the common slope. In the age group 55–59 the slope is > 1 and significantly different from the common slope. The common slope of the age groups 50–59 is also significantly steeper than that of the total number of female probands.

female (Fig 20) it was found to be significantly ($0.02 > P > 0.01$) steeper in females measured during the sixth decade of life compared to the other age groups. Such a difference could not be demonstrated in males or in other age groups or combinations of age groups in females. Although not conclusive this finding may indicate that females who at this time of life have lost more than average of their bone mass also when subjected to trauma develop a more severe post traumatic osteopenia.

B RESTORATION OF MINERAL MASS

STEINBACH (1964) pointed out that roentgenologic signs of post traumatic osteopenia may be visible up to nine years after the injury. Reports of roentgenologic healing of osteopenia following fracture usually refer to a time period within a year after the injury (BELANGER 1956, RONSE 1963).

An antero posterior roentgenograph of the knee joint of the injured limb was available in about one third of the proband (29 cases). The typical roentgenologic appearance of post traumatic osteopenia, the "spotted atrophy" (Fig 21) with subchondral and subcortical radiolucency was in most instances obvious when the roentgenograph was taken during the



Fig 21

Roentgenograph of the knee taken seven months after a transverse fracture of the lower third of the tibia and the fibula was sustained in a thirty seven year old man (Case No 66). The loss of bone mineral of the injured side was estimated to almost eighty per cent.

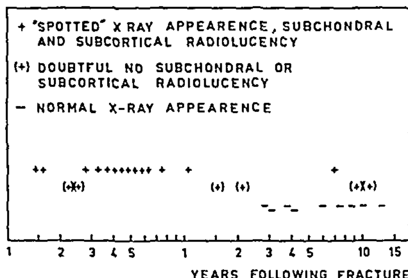


Fig 22
\ urvey of roentg nograj l taken at vari u points in time following the fracture

r t year following the fracture (Fig 22) Later occa ionally re ts of the potted atrophy although doubtful could be ob erved but al o complet ly normal roentgenographs were obtained [1] In roentgenographs including oth knees on the ame film it was virtually impo sible to di tingui h the acture from the control limb when the areal radiolucency had di appeared ven if a sub tantial difference could be recorded u ing the collimated hoton beam

Although there may be some initial re toration of lost bone in the fracture imb during the first year following the injury the progre s from that time n appears to be very low or in female none So far thi is in agreement ith clinical experience as regards generalized o teoporo i Variou type f treatment and various method for evaluation of bone ma s have o far ailed to produce convincing evidence that bone tis ue can be restored in idult females uffering from generalized o teoporosi

The data obtained in this study indicated that there was a difference etween the exes in thi re pect The information available on generalized steoporo is in males does not at this time provide a ufficient basis to li cuss whether this difference is more general or restricted to post raumatic osteopenia

In children where the findings were interpreted to be due to an increa ed ability to restore lost bone the influence of growth mu t be taken

[1] The evaluati n of the radiograms was upervi ed by Lars Andren M D The Depart ment of Radiology Malm General Ho pital Univer ity of Lun l Malm Swe len

into consideration As shown in Fig 1 an area of intense growth and remodelling the distal femoral epiphyseal line is in fact included in the measured region Healing of osteoporosis in children has been reported in a few cases of Cushing's disease However there is some disagreement as to the true mechanisms of this repair (ALBRIGHT and REIFENSTEIN 1948 MOLDAWER 1958 SKEELS 1958)

C CLINICAL IMPORTANCE OF POST TRAUMATIC OSTEOPENIA

NILSSON and SMITH (1966) found that the loss of bone mineral following fracture of the shaft of the tibia in rats was associated with a loss of strength which was out of proportion to the loss of mineral However at the present time there is no convincing evidence that in humans the fracture incidence is higher in previously fractured limb

In the present study there was no evidence that even severe post traumatic osteopenia interferes with the function of the injured limb However, in at least one elderly woman (Case 41) with severe osteopenia in the fracture leg weight bearing induced pain and osteopenia cannot be excluded as a factor contributing to the poor final status in this case

D DYNAMICS OF POST TRAUMATIC OSTEOPENIA

WENDEBERG (1961) measured the uptake of tracer in the knee two weeks after injection of Strontium 85 The measurements were carried out at various points in time following fracture of the tibial shaft The uptake expressed as the ratio of the fracture over the control limb was in the early time period following the injury low but increased during the first six months after the fracture with a factor of about five Later the ratio slowly decreased and in some cases measured up to nine years following the injury, the activity recorded over the fractured limb was less than that of the control The uptake of strontium was regarded as a measure of bone formation rate in the measured area ROSE (1966) measured the urinary calcium excretion in patients immobilized because of fracture and found an increasing excretion of calcium during the first ten days after the fracture the excretion remained high for weeks or months There was a sex difference the urinary calcium excretion was significantly higher in males

The regression of the degree of post traumatic osteopenia and time elapsed after the injury is probably not a truly linear one In fact the restoration of bone mass in males should probably be interpreted as an

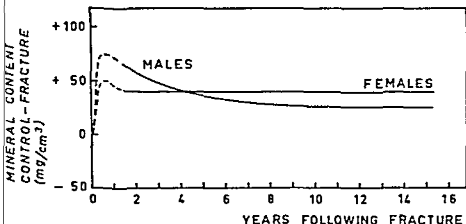


Fig 23
terpretation of the relation hip of time after fracture an l po t traumatic o teopenia (compare figures 15 and 16)

ymptotic function (Fig 23) It seem as if male although po ibly arting off with a more evere degree of osteopenia slowly improve at ast during the fir t ex even years and then remain at a level lightly etter than that of females

On the ba is of these observations the following hypothe is may be rmulated

The fracture is followed by an increa ed re orption of bone in the injured mb leading to a lo s of bone ma s particularly in the more reactive rabecular bone

Within the first months the bone ti ue begins to re pond with an icrea ing rate of bone formation which remains high during the healing roce s The formation rate keeps up with the re orption rate or pos ibly xceeds the latter allowing for a certain degree of restoration of bone mass—the spotted atrophy becomes le obvious or di appear The re orption ate now decrea es as does the formation rate at lea t in female both ventually approaching the ba e level No further restoration of bone ma s ccurs However in males there is an increa ing bone den ity for everal ears probably indicating an ability to maintain an increa ed rate of bone ormation for a con iderable time

ALBRIGHT and REIFENSTEIN (1948) believed that o teoporosis in the lderly was caused by a decrea ing bone formation rate For more than decade the treatment of osteoporosis was ba ed on this theory This oncept was reevaluated when it from tracer studies became evident that he bone formation rate wa normal in ca es with osteoporosi as compared o normal controls (DYMLING 1964) Re earch was now *directed towards*

into con ideration As shown in Fig 1 an area of intense growth and remodelling the di tal femoral epiphy eal line i in fact included in the mea ured region Healing of o teoporo i in children has been reported in a few ca es of Cu hing s di ease However there i some disagreement as to the true mechani ms of thi repair (ALBRIGHT and REIFENSTEIN 1948 MOLDAWER 1958 SKEELS 1958)

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In the present study there wa no evidence that even severe po t traumatic o teopenia interferes with the function of the injured limb However in at least one elderly woman (Ca e 11) with severe o teopenia in the fracture leg weight bearing induced pain and o teopenia cannot be excluded as a factor contributing to the poor final status in thi ca e

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Th regre i n f the degree of po t traumatic osteopenia and time elap e l after the injury i probably not a truly linear one In fact the re toration f b ne m i in male hould probably be interpreted as an

VI SUMMARY AND CONCLUSIONS

The mineral content of the distal end of the femur was evaluated in 116 of fracture of the tibial shaft The time period elapsed after the jury varied from one month to fourteen year The attenuation of a oton beam from a source of Americium 241 was measured as the beam from side to side through the epicondylar area of the femur the tissue was accounted for by the use of a water phantom of the same knee The following conclusions were made as regard the mineral ent of the distal end of the femur of the uninjured limb

1) The mineral content of the mainly trabecular bone at the epicondylar level of the femur varied between 100 and 200 mg per cc of bone

2) The mineral content was greater in male

3) The mineral content decreased with age in males a a low regression in females a more marked drop was noted beginning in the fifth decade of life

4) The mineral content was not appreciably influenced by the contra lateral injury

The following conclusions were made by comparing the mineral content the injured and the uninjured limb

1) The mineral content of the fractured limb was almost always decreased even when more than one decade had elapsed after the injury

2) The average loss of mineral was about 40 mg per cc of bone or twenty five per cent

In male the loss of mineral was more pronounced when prolonged plaster fixation or long convalescence wa required As the primary injury in the e ca es u ually was more severe it was not possible to conclude that immobilization and inactivity *per se* was the cause of the exce s lo s of mineral mass In females this effect was less pronounced

4) In females the findings suggested that endogenous factors contribute to the production of po t traumatic o teopenia

5) The lo s of bone mineral was more severe in cases with complicating factors such as osteomyelitis secondary surgery or additional injuries Again in these ca es the time of immobilization and disability was longer

(6) In males there was a tendency to restore the lost mineral during the first six to seven years following the injury In females no such tendency could be demonstrated

(7) When the fracture had occurred in childhood no significant loss of bone mineral was found This finding was believed to be due to a high ability of the young child in particular to restore lost bone

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VIII APPENDIX

Table I *Probands A Females*

Case No	Age at Accid	Follow up years	Plaster Cast months	Disability months	Fracture Type: transverse	Fracture Type: com minuted	Fracture Type: open	Fracture Type: proximal	Final Status non good	Mineral Content mg mineral/cc bone: Control	Mineral Content mg mineral/cc bone: Fracture	Repre sented in Edwards (1965) as[1]
1	16	0.7	3	4	+	+	—	—	—	190	118	PS 115
2	16	2.7	2	3	—	—	—	—	—	103	103	PS 1
3	21	1.9	2	3	—	—	—	—	—	119	101	PS 173
4	22	1.3	2	6	—	—	—	—	—	93	114	PS 13
5	24	7.8	4	13	+	—	—	—	+	227	175	CS 127
6	27	4.6	4	7	—	—	—	—	—	177	141	CS 1
7	28	0.9	2	5	—	—	+	—	—	120	101	PS 48
8	28	8.4	3	8	—	—	—	—	+	134	116	CS 2
9	29	3.5	3	5	+	—	+	—	—	157	124	CS 220
10	31	6.8	2	6	—	—	—	—	—	89	93	CS 6
11	31	9.3	3	5	—	—	—	—	—	260	121	CS 3
12	32	14.0	3	14	—	—	—	—	—	178	168	CS 4
13	33	6.3	4	6	+	—	—	—	—	154	96	CS 128
14	35	3.8	4	10	+	+	+	+	—	165	130	
15	35	15.1	3	5	—	—	—	—	—	206	173	CS 11
16	39	14.7	5	27	—	—	—	—	+	149	98	CS 39
17	40	5.3	4	13	—	—	—	—	—	129	60	
18	41	9.7	3	6	—	—	—	—	+	129	115	PS 2
19	41	10.9	11	15	+	—	—	—	—	93	38	CS 129
20	41	11.4	5	11	+	—	+	—	—	135	141	CS 221
21	41	13.2	5	8	—	—	—	—	—	114	60	CS 41
22	42	6.3	3	5	—	—	—	—	—	98	21	CS 14

23	43	9 3	4	8	—	—	—	—	—	99	80	CS 15
24	44	3 6	3	6	—	—	—	—	+	108	93	IS 4
25	44	10 1	1	7	—	—	—	—	—	157	124	CS 16
26	45	5 7	3	18	+	+	+	+	+	113	69	CS 223
27	45	11 3	4	5	—	—	—	—	—	112	131	CS 17
28	47	6 6	10	21	+	+	—	+	—	186	123	CS 130
29	47	8 6	3	12	—	—	—	—	+	154	12	CS 20
30	47	12 0	3	11	—	—	—	—	—	107	76	CS 21
31	47	12 0	3	4	—		—	—	—	139	86	CS 13
32	48	3 6	5	10	+	—	—	—	—	170	136	CS 295
33	48	9 3	8	16	+	—	+		—	113	129	CS 227
34	49	4 2	5	9	—	—		—	+	94	80	CS 24
35	51	12 3	2	17		—	+	—		94	84	CS 120
36	52	14 3	3	9	—	—				124	68	CS 27
37	54	15 0	3	10	—	—				100	107	CS 28
38	55	9 3	4	13	—	—				113	106	CS 29
39	55	4 6	6		+				+	154	30	CS 111
40	56	0 6	2	4	—	—				107	33	
41	56	0 5	3	8	+		+			83	33	IS 121
42	56	11 6	5	31	+			+		84	63	CS 131
43	59	11 1	4	8	—					58	19	IS 31
44	67	11 6		11	+			+	+	94	[illegible]	IS 112
45	67	3 3	3	6	+					131	115	IS 55
46	68	6 3	3	5						157	111	CS 18
47	72	3 6	6	8	+	—	+			152	129	CS 225
48	73	3 0	3	7	+			+		170	100	IS [illegible]
49	74	2 8	2	4	—					123	123	IS 176

Table II *Additional Cases A Cases with Complicating Factors*

Case No Sex	Age at Accid	Follow up years	Plaster Cast months	Disability months	transverse	Fracture Type com minuted	open	*proximal*	Final Status non good	Mineral Content mg mineral/cc bone Control	Fracture	Represented in Edwards (1965a)
91 F	17	4 3	6	17	+	—	+	—	+	189	118	CS 225
	Skin necrosis 27 months following accident achilles tendon lengthening posterior capsulectomy plaster cast											
92 F	58	10 8	20	36	+	—	—	+	+	54	44	CS 13[illegible]
	Slow union bone grafts 6 and 13 months following accident											
93 F	63	12 8	6	10	—	—	—	—	+	139	63	CS 47
	Osteotomy of *tibia 3 months following accident*											
94 F	64	1 9	10	15	+	+	+	—	+	72	12	PS 117
	Slow union bone graft 7 months following accident											
95 M	19	1 4	9	14	+	-	+	—	+	186	9[illegible]	FS 152
	Slow union internal fixation 5 months following accident											
96 M	35	0 4	5		+	+	+	—	+	190	110	FS 132
	Fracture of the *ankle and of the tibia plateau same leg*											
97 M	51	10 9	8	15	+	—	+	—	+	162	122	CS 251
	Osteomyelitis											
98 M	57	8 4	9		+	+	—	—	+	99	39	CS 183
	Osteomyelitis Sequestrectomy 11 13 15 and 22 months following accident											
99 M	59	13 8	7	20	+	+	+	—	—	171	105	CS 286
	Osteomyelitis											
100 M	66	8 5	8	12	+	+	—	—	+	218	189	CS 188
	Skin necrosis and *osteomyelitis* Skin graft 3 months and sequestrectomy 6 months following accident											

Table 11 *Additional Cases B Children*

Case No Sex	Age at Accid	Follow up years	Plaster Cast months	Disability months	transverse	Fracture Type com minuted	open	proximal	Final Status non good	Mineral Content mg mineral/cc bone Control	Fracture
101 F	10	7 8	3	4	+	—	—	+	—	117	139
102 F	11	7 6	[illegible]	6	—	—	—	—	—	99	140
103 F	12	3 0	2	2	+	—	—	—	—	119	139
104 F	14	8 3	2	3	—	—	—	—	—	87	[illegible]9
105 F	14	8 9	[illegible]	4	+	+	—	—	—	103	123
106 M	2	9 [illegible]	2	2	—	—	—	—	—	128	183
107 M	5	13 9	1	2	—	—	—	—	—	204	213
108 M	6	15 5	1	2	—	—	—	—	—	112	161
109 M	6	5 8	1	2	+	—	—	—	—	20[illegible]	215
110 M	7	8 9	2	2	+	—	—	—	—	[illegible]29	217
111 M	10	4 6	1		—	—	—	—	—	109	133
112 M	11	8 6	1	2	—	—	—	—	—	148	107
113 M	14	2 7	2	4	—	—	—	—	—	[illegible]	134
114 M	15	11 4	3	6	—	—	+	—	—	112	77
115 M	4	0 1	1	2	—	—	—	—	—	109	53
116 M	4	0 2	1	2	—	—	—	—	—	98	48

[1]CS and PS refer to EDWARDS (1965) Control and Prospective series respectively



AKKO PURANEN

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From the Ortopaedic Hospital of the Invalid Foundation
Helsinki Finland (Head Professor A Langenskiold M D)

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Helsinki September 1966

Jaakko Puranen

CONTENTS

INTRODUCTION

Bone transplantation is a common procedure in orthopaedic surgery. In order to speed up the operation and to minimize the operative risk it would be advantageous if it would not be necessary to take the bone required for grafting from the patient himself especially when a great amount of bone is needed as e.g. in spinal fusion involving several vertebrae. Therefore homogenous bank bone is often used in bone transplantations either as such or together with autogenous fresh bone. Bone may also be taken from the patient some weeks before operation and preserved in the bone bank to await the grafting. This method was used some years ago at the Orthopaedic Hospital of the Invalid Foundation when much bone was needed for spinal fusion in severely paralyzed patients. It was thought that autogenous bank bone is more valuable than homogenous bank bone.

The prerequisite of the use of bank bone and abandoning autogenous fresh bone is, however, that the operative results do not deteriorate. During recent years many clinical materials have been published in which the value of bank bone in demanding transplantations has been questioned. Also at the Orthopaedic Hospital of the Invalid Foundation *Riska* (1964) found during follow-up examinations of patients operated upon for scoliosis that non-union had occurred more often following spinal fusion with autogenous frozen bone than when fresh autogenous bone had been used. On the basis of this observation it was found necessary to elucidate experimentally whether the difference between autogenous fresh and autogenous bank bone is so great that it would be better to abandon the practice of taking bone from the patient and preserving it in bone bank before implantation. The tetracycline method based on labelling new bone with tetracycline was chosen for the study of this question. In the course of the investigation the primary subject widened to include the comparability of bone preserved in another way with fresh autogenous bone.)

) A preliminary report was presented at the Annual Meeting of The Finnish Orthopaedic Association November 13, 1964.

REVIEW OF LITERATURE

Theories of osteogenesis in bone transplants

Since *Ollier* laid the scientific foundation for the study of transplanted bone in 1858 literature concerning this subject has been abundant In a way it is understandable that bone grafts which play such a major role in orthopaedic surgery have provided the impetus for thorough research but actually the great number of publications is explained by the fact that the problems involved in bone transplantation are anything but unambigous The results of various investigations differ from each other and opinions concerning the process of bone formation in the grafts are perpetually controversial

One of the key questions in the study of transplanted bone is whether the resulting osteogenesis in the graft takes place through the agency of its own cells or of the host s cells Not until this question is settled by a generally accepted scientific explanation will differences of opinion on different kinds of grafts die out

In his wide and systematic investigations *Ollier* came to the conclusions that the periosteum plays the decisive role in the osteogenesis of bone transplants He believed that under favourable conditions periosteum covered bone may urvive and that the graft receives its nutrition through the periosteum

He was also the first to make a distinction in principle between autogenous homogenous and heterogenous bone In his opinion in homogenous grafts the periosteum might survive but not in heterografts Therefore he firmly rejected the use of heterogenous bone for transplantation

The doctrines of *Ollier* were prevalent until 1895 when *Barth* demonstrated that transplanted compact bone dies and is eventually replaced by bone forming surrounding tissues According to him the periosteum plays no part in re organization but perishes in the same way Neither did he find any significant differences between different kinds of bone grafts While he had some upporter he was soon subjected to widespread criticism also from practicing surgeons

G Axhausen with his extensive and scientifically planned studies (1907 1909) made a kind of synthesis of the views of *Ollier* and *Barth* He supple

mented his experimental work with rabbits and rats by histological studies of material from operated patients He showed that the bone substance in periosteum covered transplants dies but that most of the periosteum survives and possesses strong osteogenetic properties In his view autogenous and homogenous transplants do not differ in principle but only in the speed of regeneration He emphasized his preference for fresh periosteum covered autogenous bone for clinical transplantation On the other hand he completely condemned the use of heterogenous bone in surgery

The osteoblast theory is based on the investigations of *Ollier* and *G Axhausen* According to this theory new bone formation in a transplant mainly takes place through the agency of its surviving cells This view was generally accepted for years until *Levander* presented the results of his investigations in 1934 He had effected new bone formation by injecting alcoholic extracts of bone into the muscle of rabbits On the basis of his observations *Levander* believed that the reorganization of transplants occurs from the surrounding pluripotential connective tissue cells which are induced into osteogenic cells by the substances released from the dead tissue This opinion known as the induction theory (theory of metaplasia) aroused wide enthusiasm which is reflected in the literature Several investigators (*Annersten* 1940 *Bertelsen* 1944 *Oberdalhoff* 1947 *Lacroix* 1947 *Hartley et al* 1949 *Willestaedt et al* 1950 *Roth* 1950) performed various types of extraction experiments trying to isolate the substance called osteogenin by *Lacroix* The existence of such a substance was questioned by *Heinen et al* (1949) after they had demonstrated new bone formation in the muscle of rabbits following the injection of pure alcohol In experiments with other animals *Lindahl* and *Orell* (1951) as well as *W Axhausen* (1956) showed that alcoholic bone extracts and bone fragments kept in alcohol had no effect on osteogenesis

The e extraction experiments have however not proved convincing and no osteogenetic substance has been isolated On the other hand the metaplasia theory is better supported by the observations which have been made in connection with transplantations of pieces of bone As early as in 1912 *Baschkirzew* and *Petrow* on the basis of their experiments concluded that reorganization of bone transplants occurs from the surrounding tissues *Engstrom* and *Orell* (1943) implanted bone grafts frozen to −190 C into the subcutaneous tissues of humans and observed reorganization after 53 days They were certain that no living cells could have been preserved in the bone grafts and since they had also obtained similar results with fresh autogenous bone transplants they felt that new bone formation in bone grafts occurs exclusively from the surrounding young proliferative cells which through the action of dead bone tissue become transformed into osteoblastic cells

REVIEW OF LITERATURE

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which eliminates the old dualism *Lanno* in 1948 and *Urist* and *McLean* in 1952 in principle arrived at similar results on the basis of their histological studies The view that both the graft and the host are capable of taking part in osteogenesis is supported by study of *Ray* and *Sabet* in 1963 who used tritiated thymidine and by that of *Arora* and *Laskin* in 1964 who used sex chromatin as a cellular label

Different bone transplants

The first autogenous bone transplantations were performed in 1820 by *von Walther* and the first transplantation of homografts in 1878 by *Macewen* (quoted by *Chase* and *Herndon* 1955) Not until after the experimental work of *Ollier* and *G Axhausen* however did the use of bone transplantation really start in surgery In 1925 *Albee* published his experiences with 3000 and in 1924 *Lexer* his with 1000 bone transplantations *Albee* accepted only the autogenous graft According to *Lexer* a fresh autogenous periosteum covered transplant is also superior because it most certainly contains surviving cells Homogenous bone may be used if the surrounding tissues are capable of replacement Heterogenous bone on the other hand was completely condemned by *Lexer* In the beginning of the twentieth century both autogenous and homogenous bone was used as transplants The results obtained however were better with the former Besides fresh homogenous bone was not always readily available and it was feared that diseases could be transferred as a result of possibly inadequate sterilization Therefore homogenous bone grafting was given up for several decades in surgery

New methods of preserving homogenous bone presented a solution to organizatory problems The report of *Inclan* in 1942 gave a real impetus to the development of bone preservation He had preserved both autogenous and homogenous bone in from + 2 to + 5 C in citrated blood and obtained favourable clinical results which were comparable with the new bone formation in fresh autogenous grafts American surgeons especially started to develop methods of preservation In 1947 and 1951 *Wilson* published his experiences with homogenous bone transplantations in which he had used refrigeration at −20 to −29°C In his opinion bone bank bone fully corresponds to the autogenous bone transplants Several investigators (*Bush* and *Carber* 1948 *Weaver* 1949 *Hult* 1950 *Reynolds* and *Oliver* 1950 *Roth* 1950 1953 *Schmid Schmidsfelden* 1950 1954 *Bohler* 1952 1955 *Fhalt* 1954) stressed later that clinical results were equally good with fresh autogenous bone and bone bank bone

Later other methods of storage have been used such as merthiolate solution (*Reynolds et al* 1951) a polymerical plastic called Palavit (*Idelberger* 1956)

lyophilization etc. Nevertheless preservation of bone in a deep frozen state is most widely employed in many parts of the world

The doctrines of *Levander* (1934 1938) provided a theoretical basis for the operation of bone banks The role of the bone graft was considered to consist of inducing the surrounding connective tissue cells to metaplastic bone formation This makes it understandable that in the beginning homogenous and heterogenous bone were so enthusiastically thought to fulfil the same osteogenetic function as fresh autogenous bone *Judet* (1949) *Meiss* (1952) and *Guillemınet et al* (1953) went even so far as to maintain that heterogenous bone bank bone was almost equivalent to autogenous bone It was found comparatively soon however that because of biologically unsuitable properties heterogenous bone was worthless for grafting purposes in human surgery On the other hand suitable material has been prepared from calf bone by removing all organic material from it Immunologically the bone thus obtained is completely neutral Such bone prepared according to *Maatz* and *Bauermeister* and called Kieler Span has been energetically offered for sale in recent years but the excellent results of the authors (1961) and others have not found convincing support

Prior to the introduction of Kieler Span *Orell* (1934) however by macerating bovine bone had already prepared material which he called Os purum and Os novum *Orell* had mainly used this in operations by the *Albee* method At present these bone materials only survive as a curiosity in the literature

During recent decades comparative research has largely centered in autogenous bone and homogenous bank bone On the basis of clinical material only a few authors (*Magnolfi* 1958 *Kuppermann* 1959 *Arens* 1961 *Rehn* 1964 *Schweemmer* and *Conten* 1964) have been completely content with the bone bank In 1959 when reporting on his large operative series *Burke de la Camp* maintained that although a fresh autograft is replaced by new bone more rapidly than frozen bone the difference is nevertheless not striking and plays no essential role Many authors emphasize that bone bank bone cannot replace autogenous fresh bone and that the indications for its use must be carefully weighed (*Sieber* 1954 *De Tomasi* 1955 *Schoch* 1956 *Buser* 1959) In 1959 on the basis of their clinical experience *Carnesale* and *Spankus* stressed that preserved homogenous bone may be used when the available supply of autogenous bone is not adequate for the particular situation or when the hazard of surgery is materially increased by obtaining the autogenous bone The percentage of failures has generally been over 20 in published series where bank bone was used (*Report of the Committee to Study the Preservation of Bone* 1955 *Bosworth et al* 1955 *Hackethal* 1956 *Moe* 1958 *Kuska* 1964)

Since the enthusiasm prevailing at the time of establishing the bone banks waned in the opinion of most investigators histological studies have demon

strated that regeneration of fresh autogenous bone occurs more rapidly than that of homogenous bone *Stringa* in 1957 and *Kingma* and *Hampe* in 1964 studied the rates of vascularization in autogenous and frozen bone by histological and injection techniques They found that vascularization in homogenous bone was two to three times slower and less complete than in an autograft

The actual controversy emerges in attempts to find a reason for the superiority of autogenous bone The role of immunological activity has been widely investigated but without conclusive results Some investigators (*Zeiss et al* 1960 *Sabet et al* 1961) believe that antigen antibody reaction reduces revascularization of homogenous bone

The possibility that the superior osteogenetic capacity of autogenous bone is due to relatively intricate immunological factors has resulted in the use of various deproteinized and decalcified bones in order that antigen antibody reaction may be avoided In experiments with dogs *Heiple et al* (1963) compared different bone grafts They found that regeneration in decalcified irradiated frozen and deproteinized homogenous transplants occurred more slowly than in freeze dried homogenous bone or frozen bone of these two new bone formation was more rapid and more satisfactory in lyophilized bone than in frozen bone In their work they established the antigenic status of different transplants They found that freezing and lyophilization destroy the antigenicity *of homogenous bone In this way they arrived at the conclusion that* perhaps the above mentioned methods of preservation do not exert the same effect upon the inductor mechanism In these investigations they employed as control fresh autogenous bone which proved definitely superior to other bone grafts The results of the study of *Heiple et al* suggest that antigenicity does not play any decisive part in the regeneration of bone

De Bruyn and *Kabisch* (1955) stress the importance in osteogenesis of osteogenetic material released from the dead bone transplant They studied new bone formation in transplants implanted in the muscle of rabbits their observation period ranged from 6 to 129 days New bone formation occurred in 86 per cent of the fresh autogenous grafts whereas in homogenous and autogenous frozen bone it could only be found in 0 to 8 per cent They explained this remarkable difference by assuming that freezing destroys the osteogenetic inductor On the other hand no histological evidence could be found to suggest that surviving cells in autogenous bone contribute to the reorganization of the transplant

Contrary to this latter investigation an increasing number of investigators have now confirmed that osteogenic cells do indeed survive in fresh autogenous bone In 1951 *Reynolds* and *Oliver* were still of the opinion that a slight time factor was the only difference in reorganization between autogenous fresh bone and bank bone but a few years later they agreed that the difference is evident

and believed that this is partly due to the cells surviving in an autogenous graft Thus *Reynolds* (1955) said that he had almost entirely abandoned the use of bank bone in spinal fusion

The difference between fresh autogenous and frozen homogenous transplants has been studied by *Vainio* (1957) in experiments with rabbits imitating the technique of spinal fusion by the *Albee* method After the interval required by the autogenous graft to become fully regenerated the homograft had still preserved its size and original shape Regeneration occurred most easily when the autogenous bone was covered with periosteum On the basis of his experiments *Vainio* believed that at least a part of the cells survives in autogenous transplants Entirely similar results are reported by *W Axhausen* (1962) in his extensive and thorough histological investigations He concluded that the bone bank in the course of this development will become unnecessary

It would seem that after decades of investigations we are again returning to the basic views already presented at the end of the last century by *Ollier* and *G Axhausen* Bone-bank bone is nevertheless still used all over the world even in very exacting bone transplantations Large parts of bones (e g the femur) may be replaced by homogenous bone bank bone Whether homogenous bone is preferable to a metallic endoprosthesis in replacing a major portion of a bone is a question which arises when the use of autogenous bone is impossible for quantitative reasons

PROBLEMS

It is obvious that even in the future the use of bone transplants will retain a place in orthopaedic surgery notwithstanding the fact that certain method of metal fixation e.g. in pseudarthroses have reduced the need for bone grafting just as drug treatment has often rendered arthrodesis or spondylodesis unnecessary. On the other hand bone transplantation has gained new indications. Although the study of bone transplantation has aroused wide interest the problems involved are anything but solved. Even though matters have been somewhat clarified in recent literature so much controversy still prevails that further investigations are called for. Since bone preserved in a frozen state is continually used in many parts of the world there is every reason to try to find out whether and to what extent such bone is equal to fresh bone in transplantation. Also it is important to know how the handling of an autogenous bone transplant affects its osteogenetic properties. These questions are significant in surgery because osteogenetically low grade bone leads to poor operative results.

In surgery the biological value of a bone transplant is determined by its osteogenetic capacity and by the quality and speed of its reorganization. Fresh autogenous bone has been considered to be the best for grafting purposes but whether its osteogenetic capacity is essentially different from that of preserved bone is a problem which can only be solved by attempting to provide answers to the following questions:

1) Are there any differences in reorganization between a fresh autogenous transplant and
   a) autogenous bone preserved in a frozen condition
   b) homogenous bone preserved in a frozen condition
   c) autogenous bone preserved in the open air or in normal saline solution at room temperature
   d) autogenous bone preserved in blood at 37°C?
2) What role in reorganization of the graft is played by the time factor?

The difference between a fresh and a preserved transplant is of theoretical interest. However the main purpose of this study has been to try to elucidate the

question whether an immediately transplanted autogenous bone graft is much more quickly and completely incorporated into the skeleton than a preserved autogenous or homogenous graft if so it makes the use of fresh autogenous grafts preferable in orthopaedic surgery whenever possible

In the process of bone transplantation new bone formation occurs both in the graft and the host bone In the former bone undergoing necrosis is replaced by new bone This process involving both resorption and apposition is called *reorganization of the transplant* New bone formation in the host bone on the other hand serves to fix the graft and finally enclose it in the host bone In this investigation the *osteogenetic capacity* of the transplant implies the ability of the graft to be reorganized and to stimulate new bone formation in the host bed

MATERIAL AND METHODS

Material

With the exception of six adult rabbits the study was performed on rabbits aged 5 to 15 weeks. In young rabbits the osteogenetic processes in bone are more rapid than in adults, so that regeneration of transplants occurs in them in a far shorter time.

A total of 136 rabbits were operated on, and 15 of them died postoperatively. This left 121 rabbits, of which three rabbits with a plastic tube as the transplant were added to the control series.

Thus there were 118 rabbits available for tetracycline and histological examinations. In nine rabbits two grafts were implanted in both femurs, in five one graft in the left femurs and the other in the right femurs, and in the remaining 104 rabbits two or three grafts were implanted in the left femurs only. Thus the material consisted of 127 experiments. 26 femurs with grafts were reserved for both tetracycline and histological examinations.

Distribution of the material according to the methods of study:

Experiments with		
tetracycline	94	(93 rabbits)
histological method	7	(7)
tetracycline and histological method	26	(18)
Total	127	(118)

Surgical technique

The operations were performed aseptically under local anaesthesia (0.25 per cent Xylocain Exadrin® Astra). The lowest ribs, either adjacent ones or from opposite sides, were used as transplants containing only diaphysial bone. The periosteum was occasionally preserved in order that observations could be made as to its role in reorganization (Table 3 and 4).

The transplants were grafted into the left femur, in some cases in both femurs. One tip of the transplant was lying on the surface of the femur

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and lyophilization techniques for the preservation of bone but different methods are not known to account for decisive differences in osteogenetic capacity Prior to implantation the bone bank bone was placed in normal saline solution warmed to room temperature

Bone preserved in whole blood Immediately after the removal of an autogenous rib with or without periosteum it was placed in a glass tube containing heparinized penicillin containing whole blood of the same rabbit The tube was then kept in an incubator for 3 or 5 days at 37 C

Autogenous bone preserved in the open air or in physiological saline solution at room temperature Two adjacent ribs without periosteum were removed one of which was immediately grafted to the femur and the other was left in room temperature either to dry in the air or immersed in physiological saline The bone was kept dry for 1 or 2 hours and in saline solution for 1 2 or 3 hours before it was grafted to the same femur where the fresh bone had been previously grafted

Investigation with tetracycline

In this study the reorganization of bone transplants was followed by means of tetracycline deposited in the bone

Tetracycline in bone labelling

A surgeon *John Belchier* in 1736 reported that the bones of pigs which had been fed on madder were coloured red with this dye *Duhamel* between 1739—1743 and *Hunter* between 1760—1770 used madder as an aid in the study of bone growth (quoted by *Sissons* 1956) In 1957 *Milch et al* reported that antibiotics of the tetracycline group have a special affinity for bone tissue where they have the ability to fluoresce in ultraviolet light Because of its striking and clearly discernible yellow fluorescence and because of its lesser toxicity tetracycline is superior to alizarin in bone research

Tetracycline given by mouth or parenterally is distributed diffusely into the organism but after 24 hours it has already disappeared from the soft tissues and only remains in calcified tissues Tetracycline labelled bone appears as yellow stained clear cut bands which are parallel to and in the substance of the lamellae The bands do not cross lamellae or cement lines The labelled band widths are a direct function of the duration of tetracycline medication and the rate of mineralization of osteoid When life continues after withdrawal of the

tetracycline medication the labelled bone and calcified cartilage become covered by unlabelled bone and calcified cartilage unless appositional growth ceases during drug administration Once deposited in bone tissue the tetracycline and its fluorescence remain until resorption of the bone results in its disappearence This implies that in adults the fluorescence may persist for years but in a growing individual it may disappear fairly rapidly

From the point of view of research on bone the essential fact is that like alizarin and radioactive calcium tetracycline is taken up by the new bone On the other hand tetracycline is not deposited in cartilaginous or osteoid tissues which therefore in ultraviolet light show a bluish fluorescence Neither has it been found that tetracycline is deposited in necrotic bone (*Rokkanen et al* 1965)

According to *Harris et al* (1962) tetracycline labels all bony surfaces but surfaces undergoing resorption and inactive surfaces showing fluorescence immediately after tetracycline injection rapidly lose their fluorescence On the other hand *Harris et al* found some diffuse distribution of tetracycline and presumed that it followed the distribution of calcium in the form of secondary mineralization and long term exchange According to *Hulth* and *Olerud* (1962) the diffuse distribution of the fluorescence is greatest during the first 24 hours because the tetracycline is then not sufficiently firmly fixed to the bone but is probably in the hydration shell surrounding the apatite crystals Fluorescence may also appear around many lacunae this phenomenon being in the opinion of *Harris et al* probably an artifact Fluorescence may also occur in connection with so called marginal sclerosis

The tetracycline molecule is bound in unaltered form to superficially situated calcium atoms in crystal nucleation sites in freshly formed bone Polysaccharides and collagen may play a part in this binding The relatively high content of tetracycline in freshly mineralized bone is explained by the fact that the crystals are then small and form a wide surface area suspended in tissue with maximum content of water and high reactivity of calcium deficient apatite In less than 24 hours after mineralization calcium deficient apatite is transformed into a less reactive form mature hydroxyapatite In addition the crystals grow larger and the amount of water decreases and the matrix becomes compact following which large molecules such as tetracycline can no longer penetrate into the organic matrix (*Urist* and *Ibsen* 1963)

Many writers (*Milch et al* 1958 *Frost et al* 1960 *Harris et al* 1962 *Hulth* and *Olerud* 1962) are of the opinion that the tetracycline method is most suitable for investigation concerning the appositional growth of bone Despite the fact that tetracycline may also become deposited elsewhere than in new bone this method nevertheless constitutes an interesting and adequately reliable means

of studying the reorganization of transplants Histological methods that have mostly been used until now leave much scope for interpretation which is seen in the fact that in similar investigations different authors have arrived at opposite results One drawback of the tetracycline method is that it is difficult to determine quantitatively the distribution of tetracycline (*Harris et al* 1962 *Landerhoeft et al* 1962) but one must be satisfied with the qualitative demonstration of its deposition in the bone by means of fluorescence

Own experiments with tetracycline

Since tetracycline marks the places where new bone is being formed yellow fluorescence in a transplant signifies the occurrence of reorganization in the transplant Reorganization proceeds through resorption and apposition (*G Axhausen* 1907) At first the new bone is woven bone but after final reorganization the structure of the graft resembles the lamellary structure of the host bone Therefore fluorescence reflected by the tetracycline accumulated in host bone presents a point for comparison in judging the degree of reorganization of the transplant

Oxytetracycline (Terramycin® Pfizer)) was used in single doses of 50 mg per kilogram of body weight subcutaneously this being the generally employed dose

The tetracycline experiments were divided on the basis of the method of administration into two series as follows

Series I the tetracycline injection was administered after the bone grafting

Series II the tetracycline was injected on two successive days two or three days prior to the taking of the rib for preservation

Series I gives information about the new bone formation (apposition) in the graft and Series II about the resorption of the original tetracycline labelled bone transplanted into the femur In this way the reorganization can be studied from two opposite points of view As tetracycline virtually labels the bone formed during eight hours after the injection (*Tapp* 1966) repeated doses had to be administered in Series I usually at intervals of one week Tetracycline was often administered on two successive days especially if the time of observation was short

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) The author is much indebted to Pfizer for kindly supplying the Terramycin used in this study

The distribution of tetracycline experiments according to the nature of the transplants is presented in the table 1

TABLE 1 — *Experiments with tetracycline*

Combination of rib transplants	Number of experiments Series I	Series II
Autogenous fresh bone Autogenous frozen bone	59 (55)	10 (10)
Autogenous fresh bone Homogenous frozen bone	12 (8)	
Autogenous fresh bone Autogenous bone preserved in whole blood Autogenous or homogenous frozen bone	5 (5)	
Autogenous fresh bone Autogenous bone preserved in the open air or saline solution	26 (25)	8 (8)
	102 (93)	18 (18)
Total number of experiments	120 (111)	

In parentheses the number of rabbits

Four autogenous bones preserved in blood and six homogenous frozen bones were compared with autogenous frozen bone in these cases altogether three bones were grafted into the same femur because every combination included a fresh autograft This was thought to be the best way to find out possible differences

The rabbits in Series I were killed so that the time interval between the grafting of the ribs and the last tetracycline injection ranged from 6 days to three months with at least 48 hours after the last injection in order to avoid *short term exchange* The rabbits in *Series II* were *killed* from 2 weeks to 5 months after the grafting

Examination of the grafts and photography Immediately after killing the animals the femur with transplants was prepared free of soft tissues and preserved by deep freezing The specimens were examined with a stereomicro scope in ultraviolet light (HBO 200 W) using UG 1 as exciter filter From specimens preserved in a dark deep frozen state the fluorescence did not disappear to any noteworthy extent over a year The specimens were examined macroscopically both as such and as transverse and longitudinal sections The sections were prepared by sawing through the femurs with the grafts and grinding the resulted surface Tetracycline incorporation in the transplants

could be demonstrated clearly by low magnification of the section surface Eight specimens were embedded in methyl methacrylate and ground to thickness of 100 μ for microscopic examination

The macroscopic specimens were photographed in reflected light with a Leic Aristophot macroscopic photographic apparatus using Agfa daylight film CT 1 As exciter filter before the ultraviolet light a UG 1 was used while in th camera a Wratten 2 B was used as the barrier and a CC20R as the compen sating filter Since demonstration of the results is based on yellow fluorescenc only colour photography could be employed A black and white picture does n give a marked view of the reorganization of the bone transplant because th new bone formation occurs diffusely without distinctive growth lines

Estimation of tetracycline fluorescence Reorganization of the transplant wa estimated visually on the basis of yellow tetracycline fluorescence The whol graft was assessed except the implanted part that was inside the femur Th scale used in estimating the relative amount or loss of fluorescent bone in th transplant was none or minimal scanty considerable abundant

The whole tetracycline material is tabulated using the following scales (Tabl 3 4 5)

Series I (formation of new bone labelled with tetracycline)

None or minimal	=	hardly any yellow fluorescence
Scanty	=	scattered strong yellow fluorescence
Considerable	=	strong yellow fluorescence in large areas
Abundant	=	strong yellow fluorescence throughout the graft

Series II (resorption of the original tetracycline labelled bone)

Loss of yellow tetracycline fluorescence in the graft was examined by com parison with a rib labelled with tetracycline This rib was taken at the sam time with a future graft prior to the transplantation and preserved in a froze state to serve as a control

None or minimal	=	hardly any loss of yellow fluorescence
Scanty	=	scattered loss of yellow fluorescence
Considerable	=	no yellow fluorescence in large areas
Abundant	=	hardly any yellow fluorescence discernible

Histological examination

Although the investigation was performed with the tetracycline method was found desirable to include histological examination as well (Table 2) Seve rabbits were reserved for histological survey only On the other hand 2 femurs with grafts were examined by both tetracycline and histological method

In 16 cases the femur with transplants was cut in the middle one end being reserved for histological and the other for tetracycline fluorescence examination Histological and tetracycline sections prepared from the place of the cro s cut present a mutually supplementary and comparable picture of the reorganization occurring in the grafts

TABLE 2 — *Histological material*

Preserved bone implanted into same femur with the fresh autograft	Number of experiments and time of observation									
	days		weeks					months		
	6–8	14	3	4	5	6	7	2	3	
Autogenous frozen bone	6 (1)	1 (1)	1	3 (1)	1 (1)		2	2 (2)	4 (1)	20
Homogenous frozen bone	1		1	2		1				5
Autogenous bone preserved in blood		2								2
Autogenous bone preserved in the open air				4		2				6
Totals	7	3	2	9	1	3	2	2	4	33

) In parentheses the number of experiments with histological method only In the remaining cases tetracycline method was used as well In these experiments the time of observation was counted from grafting to last tetracycline injection The rabbits used for these experiments were killed two days later in order to avoid short term exchange

) As third implanted autogenous frozen bone

In assessing the histological picture attention was paid both to the topography of the specimen and viability of the bone Bone tissue was considered vital when its lacunae contained an osteocyte whose nucleus was not pycnotic The preparations were decalcified with EDTA and stained with Weigert — van Gieson s hematoxylin

Control series

In order to make it possible to asses the role of the transplant in bone forming of the host bone a piece of plastic tube was used instead of grafts The ends of this plastic tube were implanted in a distal and proximal burr hole on the ventral surface of the femur Nine experiments were included in this series in 3 rabbits the plastic tube in the both femurs (6 experiments) in 3 rabbits the plastic tube in the right femur bone grafts in the left femur Tetracycline injec

tion was performed according to the method already described (Series I) The rabbits were killed after one to seven weeks

The shape of the femur with the transplants was compared with that of the opposite femur without transplants In this way an idea of the effect of the transplants on the host bone was obtained

In Series II (resorption of the original tetracycline labelled bone) a rib labelled with tetracycline was taken at the same time with a future transplant prior to the transplantation and preserved in a frozen state for comparison of the degree of resorption in the graft

RESULTS

In the present experiments two or three pieces of ribs one of which was the autogenous fresh transplant were grafted mostly into the same femur This was thought to provide a reliable means for the comparison of the reorganization between the different transplants The results are presented according to the combination of the transplants used in the experiments As the material (page 19) indicates particular emphasis was laid on the investigation with tetracycline The transplantation of the fresh and frozen autogenous ribs into the same femur forms numerically the most common combination (Table 1)

Autogenous fresh bone and autogenous frozen bone

Comparison between autogenous fresh and autogenous frozen transplants was performed on the basis of the formation of the tetracycline labelled new bone (Series I) and on the basis of the resorption of the original tetracycline labelled bone (Series II) The former comprises the main part of the experiments The results are presented in the table 3 The investigation with tetracycline was completed and controlled by histological examination

Autogenous fresh bone

Formation of new bone labelled with tetracycline (Series I) In fresh autografts lively reorganization began soon after the implantation At 6 to 7 days some tetracycline was already incorporated in the fresh transplant After this the tetracycline incorporation which indicates new bone formation increased quickly (Figs 2 3 5 6) After a month the fresh autograft was already far reorganized (Figs 7 8 10) In 2 to 3 months the transplants resembled the lamellary structure of the host bone (femur) (Figs 12 11)

In a fresh autograft the reorganization began in the end of the rib implanted in the femur However more tetracycline incorporation could be seen in the middle part of the transplant than in its ends (Fig 9) There could even be more

TABLE 3 — *Autogenous fresh graft (aF) and autogenous frozen graft (aB)*
Series I (tetracycline injection after grafting)

No of rabbit	Age at transplantation (weeks)	Time of observation (days) (from grafting to last inj)	Autograft transplanted after being kept frozen (days)	Tetracycline fluorescence in the graft: Autogenous fresh graft				Autogenous frozen graft				Remarks
				None or minimal	Scanty	Considerable	Abundant	None or minimal	Scanty	Considerable	Abundant	
141 s	6	6	3		+			+				
141 d	6	6	3		+			+				
142 s	6	6	3		+			+				pe (aF)
53	8	7	2		+			+				
135 s	7	8	4		+			+				Fig 16
135 d	7	8	4		+			+				pe (aF)
1	5	10	3		+			+				p (aF)
22	13	10	6			+		+				pe (aF) Fig 2
26	13	10	6		+			+				Fig 4
33	6	14	6			+		+				pe (aF aB)
6	34	14	7		+			+				
38	7	15	2		+			+				pe (aF)
39	7	15	2			+		+				
40	7	15	3			+		+				pe (aF)
41	7	15	3			+		+				
42	7	15	4		+			+				
44	7	15	1			+		+				pe (aF) Fig 5
45	7	15	1			+		+				pe (aB)
46	7	15	5		+			+				
47	7	15	5		+			+				pe (aF+aB)
12	8	15	3		+			+				aF→s aB→d
11	9	18	3			+			+			
2	5	20	3		+			+				aF→s aB→d
5	30	21	5			+		+				
8	30	21	3			+		+				
29	6	21	10			+		+				
137 s	6	21	3			+		+				pe (aF)
5	5	22	3			+			+			aF→s aB→d
32 d	7	22	19			+			+			pe (aF)
13	7	28	5			+		+				
17	7	28	7			+		+				Fig 9
30	7	28	5			+		+				pe (aF)
55	7	28	5			+		+				
124	7	28	3				+		+			

Continued

Table 5 — Continued

No of rabbit	Age at transplantation (weeks)	Time of observation (days) (from grafting to last inj)	Auto graft transplanted after being kept frozen (days)	Tetracycline fluorescence in the graft: Autogenous fresh graft: None or minimal	Scanty	Considerable	Abundant	Autogenous frozen graft: None or minimal	Scanty	Considerable	Abundant	Remarks
125	7	28	7				+		+			
126	7	28	5				+		+			
9	56	28	1			+		+				aF→s aB→d
136 s	6	28	3			+			+			
139 s	6	28	5			+		+				
23	10	30	6				+	+				Fig 8
10	7	55	5				+		+			aF→s aB→J Fig 10
32 s	7	35	6			+		+				pe (aF+aB) Fig 11
57	10	42	12				+		+			Fig 7 the th rd g ft n the same fem was n autog bo e pre rved i Pal v t It h d sc ty fluoresce ce l k the fro n bone
153	40	49	3			+		+				pe (aF)
134	10	49	3				+	+				Fig 20
16	7	60	6				+		+			
48	6	60	1				+			+		pe (aF)
49	6	60	1				+		+			pe (aB)
50	8	60	2				+		+			Fig 12
51	8	60	2				+		+			pe (aF+aB)
54	7	69	6				+			+		pe (aF+aB)
15	7	84	6				+		+			
21	15	90	6				+		+			Fig 13
27	6	90	6				+		+			pe (aF+aB)
131 s	7	90	3				+		+			pe (aF+aB) Fig 21
151 d	7	90	3				+		+			pe (aF+aB)
132	7	90	5				+		+			
88	6	90	7				+		+			Fig 14
92	6	90	7				+		+			

Continued

Table 3 — Continued

Series II (tetracycline injection prior to grafting)

No of rabbit	Age at transplantation (weeks)	Time of observation (days) (from grafting to killing)	Autograft transplanted after being kept frozen (days)	Loss of tetracycline fluorescence — Autogenous fresh graft: None or minimal	Scanty	Considerable	Abundant	Loss of tetracycline fluorescence — Autogenous frozen graft: None or minimal	Scanty	Considerable	Abundant	Remarks
73	8	14	3			+		+				
83	6	21	3			+		+				Fig 15
74	8	25	3			+			+			
84	6	28	3				+		+			
75	8	30	3				+			+		
76	8	30	3				+		+			
77	8	42	3				+		+			
85	6	42	3				+		+			
86	6	42	3				+		+			pe (aF)
87	6	90	3				+			+		pe (aF)

Explanations

s (sinister) or d (dexter) after number in which femur the grafts were implanted sections for histological examinations as well

aF→s only aF implanted in the left femur

aB→d only aB implanted in the right femur

pe(aF) periosteum in aF

tetracycline within the transplant than on its surface (Figs 4 6) Strong yellow fluorescence also occurred in the bone marrow (Fig 3) Anywhere on the surface of the transplant new bone might be seen as a deposit resembling a gnarl on the side of a tree (Fig 16)

In the fresh autograft the new bone formation labelled with tetracycline progressed rapidly and the transplant was in the process of remodelling So much new bone could be formed in the fresh transplant about to reorganize that the graft became 2–3 times thicker than it had originally been making it difficult to say where the original transplant had been (Figs 7 20) After the fresh autograft had been lamellarly reorganized it became smaller and lost its original shape and curvature (Figs 12 13) It lay atrophied and thin on the femur as far as it was not incorporated in the host bone

Histological findings 8 to 10 days after the transplantation most of the lacunae of autogenous fresh transplants were empty However the fresh auto grafts exhibited a picture suggesting that vital tissue was present scattered here and there (Fig 17) Most commonly bone tissue containing osteocytes was found at both the external and internal surfaces of the graft Nucleus containing lacunae might be seen in the bone marrow and around the haversian canals New immature bone was often encountered in well discernible layers on the external surface of the graft while especially in the superficial parts of the graft itself were living areas of lamellary bone (Fig 16) In all within 8 to 10 days vital bone tissue was found in the fresh autograft in the form of islands of immature bone and as normal bone with nucleus containing lacunae The occurrence of the latter suggested that some parts of the transplant could remain alive

In the fresh autograft the changes occurred rapidly Increasing porousness and *vital bone islands modified the shape of the graft* Numerous trabeculae filled the bone marrow cavity and the transplant could grow considerably larger than it was originally (Fig 20) In about 1 to 6 weeks only a small amount of necrotic bone tissue could be discerned in the fresh graft Within three months the fresh graft was reorganized and its lamellary structure completely corresponded with that of the host bone (Fig 21) At this stage the transplant had definitely attained the shape of a tubular bone but most commonly it was thinner and more flattened in comparison with the original transplant

Apparently after 1 to 2 months when the dead bone had almost entirely been replaced by living bone immature bone tissue started to change into mature bone the structure of the transplant became more dense and the graft thickened during reorganization became smaller through resorption and again acquired distinct bone marrow cavity (Fig 21)

Autogenous frozen bone

Formation of new bone labelled with tetracycline (Series I) In the frozen autograft scanty amounts of fluorescent bone were actually seen only after 3 weeks The yellow fluorescence increased very slowly Thus after about 6 weeks (Fig 7) the degree of osteogenesis as indicated by tetracycline fluorescence in the frozen bone was not yet on the same level as that of the fresh autograft at 10 days (Figs 2 4) and during 3 months (Figs 13 14) not more tetracycline was incorporated in the frozen bone than during 2 weeks in the fresh bone (Fig 3) In adult rabbits this difference in reorganization was perhaps still clearer Thus after 7 weeks the fresh autograft was almost

completely reorganized whereas the frozen autograft was as if recently transplanted (Fig 20)

In the frozen autograft tetracycline incorporation was seen first in the end *of the transplant implanted into the femur and then in that end which was* lying on the femur Reorganization of the transplant with the exception of the end parts characteristically began from the part situated most closely to the fresh autograft (Fig 7) Usually the frozen bone became attached to the fresh autograft, as the reorganization of the latter progressed and obviously as a result of new bone formation originating from the fresh autograft

When the transplants were studied in low magnification it was seen that the cortical layer of the frozen bone looked quite compact for several weeks whereas in the fresh bone it was porous (Figs 2 15) On the other hand in reorganization of the frozen bone the resorptive component was in the foreground While in the fresh autograft creeping apposition occurred concurrently with resorption in the frozen bone the apposition phase lagged markedly behind

Histological findings 6 to 10 days after transplantation the frozen bone showed no living cells and empty lacunae made it porous (Fig 16) In this phase the fresh autograft was porous too but in frozen autograft this porousness then persisted without change for weeks While reorganization was thriving in a fresh transplant in frozen bone it was poor Vital bone did not appear until after 3—4 weeks in small amounts Within 3 months (Fig 21) there was approximately as much vital bone in frozen bone as in a fresh transplant 2 weeks after implantation

When a few weeks had passed since the transplantation the fresh and frozen autografts had often grown firmly together Histologically it might be seen that the living bone tissue of the fresh transplant mostly ended with a sharp line of demarcation against the necrotic tissue of the frozen bone The corresponding phenomenon is illustrated with homogenous bone in the figure 19 However there might be scattered osteocyte containing lacunae in the preserved bone indicating the beginning of reorganization In the frozen autograft vital bone was mostly first seen in the shaft of the graft in the part that was next to the fresh transplant In the bone marrow living bone islands were also encountered earlier than in other parts of the graft

The effect of the grafts on the host bone

Formation of new bone labelled with tetracycline (Series I) After the transplantation bone formation also occurred in the host bone itself This began immediately after the implantation of the transplants from the holes for fixing

Histological findings 8 to 10 days after the transplantation most of the lacunae of autogenous fresh transplants were empty However the fresh auto grafts exhibited a picture suggesting that vital tissue was present scattered here and there (Fig 17) Most commonly bone tissue containing osteocytes was found at both the external and internal surfaces of the graft Nucleus containing lacunae might be seen in the bone marrow and around the haversian canals New immature bone was often encountered in well discernible layers on the external surface of the graft while especially in the superficial parts of the graft itself were living areas of lamellary bone (Fig 16) In all within 8 to 10 days vital bone tissue was found in the fresh autograft in the form of islands of immature bone and as normal bone with nucleus containing lacunae The occurrence of the latter suggested that some parts of the transplant could remain alive

In the fresh autograft the changes occurred rapidly Increasing porousness and vital bone islands modified the shape of the graft Numerous trabeculae filled the bone marrow cavity and the transplant could grow considerably larger than it was originally (Fig 20) In about 4 to 6 weeks only a small amount of necrotic bone tissue could be discerned in the fresh graft Within three months the fresh graft was reorganized and its lamellary structure completely cor responded with that of the host bone (Fig 21) At this stage the transplant had definitely attained the shape of a tubular bone but most commonly it was thinner and more flattened in comparison with the original transplant

Apparently after 1 to 2 months when the dead bone had almost entirely been replaced by living bone immature bone tissue started to change into mature bone the structure of the transplant became more dense and the graft thickened during reorganization became smaller through resorption and again acquired distinct bone marrow cavity (Fig 21)

Autogenous frozen bone

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Resorption of the original tetracycline-labelled bone (series II)

The differences in reorganization between autogenous fresh and autogenous frozen bone were not only studied from the point of view of formation of new bone but also as regards resorption of transplanted bone (Table 5). The bones of rabbits were labelled with tetracycline on two successive days. Two ribs, one for grafting, the other for the control series, were taken after 2 to 5 days and preserved in a deep frozen state. After 3 days a rib from the opposite side was taken and both the fresh and frozen ribs were implanted according to the method described above.

Since the transplant is replaced by new bone, resorption forms an essential part of reorganization. It removes the tetracycline deposited earlier in the bone. Thus, the sooner a bone graft is reorganized, the more quickly the tetracycline disappears. The loss of yellow fluorescence in the graft was compared with the rib labelled with tetracycline taken prior to the transplantation. As can be seen from the figure 15 and table 3 resorption occurred definitely more rapidly in a fresh bone, fully corresponding with the observations in the preceding series based on the deposition of tetracycline in the bone after transplantation.

The effect of the time of preservation

Autogenous frozen bone was preserved for 1 to 19 days in a frozen state. The time of preservation within these limits had no effect upon the rate of uptake of tetracycline in the transplant. This observation was further verified in a series of 14 rabbits. In 10 cases (2 litters, rabbits Nos 38—47) the time from grafting to last tetracycline injection was 15 days and in 4 cases (the same litter, rabbits Nos 48—51) 2 months. In this series the time of preservation varied in pairs from 1 to 5 days.

Autogenous bone preserved in Palavit. For the sake of curiosity an autogenous rib was preserved for 12 days in a plastic substance called Palavit. Autogenous frozen bone was implanted in the same femur as a third graft in addition to a fresh transplant. This result did not differ from that observed in other methods of preservation (Fig. 7).

Comments

Although new bone formation varied to some extent depending on individual factors and the different specimens are not absolutely directly comparable with each other, it was nevertheless proved that a fresh autograft without exception incorporated tetracycline decidedly faster than a frozen autograft.

The histological observations are in agreement with those obtained by means of the tetracycline method Of those preparations of which both histological and tetracycline sections were taken from the same place it could be seen that bone containing osteocytes was present in the place where yellow tetracycline incorporation was seen However 8—10 days after implantation osteocyte containing lacunae were seen in the histological section especially in the superficial parts of the transplant where no tetracycline had occurred This observation suggests that in immediately transplanted autogenous grafts osteocytes *might survive after transplantation (Fig 16) Some investigators (Albee 1944 Vainio* 1950 *Vainio* and *Solonen* 1957) hold the view that a part of the fresh autograft is able to survive and even to become a part of the regenerated transplant

Autogenous fresh bone and homogenous frozen bone

In the present study 14 homogenous frozen bones were grafted The material (Table 4) provides the possibility of comparing homogenous frozen bone not only with autogenous fresh bone but also with autogenous frozen bone bone preserved in whole blood and bone preserved one hour in the open air (spec 140 d in the table 5) In this way the mutual differences between these types of bone were most easily recognized

As regards the deposit of tetracycline homogenous frozen bone was not essentially different from the other preserved bones (Fig 6) The histological findings in homogenous frozen bone (Figs 17 19) were quite the same as those in autogenous frozen bone described on the page 55

Autogenous fresh bone and autogenous bone preserved in whole blood at 37°C

As a counterbalance to frozen bone it was thought relevant to investigate whether preservation of bone in the experimental animal s own blood at 37°C prevents loss of its osteogenetic capacity In order to make comparison with frozen bone also feasible frozen bone was grafted into the same femur as a third transplant (Table 1) Two of the five rabbits were chosen for histological survey as well the results are presented in the table 4 In the light of this small experimental series (5 rabbits) no differences from frozen bone could be observed either with tetracycline (Figs 5 6) or with histological methods (Fig 18)

one or two of the following pr[illegible] [illegible] bones | *homogeneous fro[illegible] bone (hB)* / *autogenous bone [illegible] in whole blood (aBl)*

No of rabbit	Age at transplantation (weeks)	Time of observation (days) (from grafting to last inj)	Autograft transplanted after being kept frozen (days)	Autograft transplanted after being kept in blood (days)	Homograft transplanted after being kept frozen (days)	Tetracycline fluorescence in the graft: First graft: None or minimal	First graft: Scanty	First graft: Considerable	First graft: Abundant	Second graft: None or minimal	Second graft: Scanty	Second graft: Considerable	Second graft: Abundant	Third graft: None or minimal	Third graft: Scanty	Third graft: Considerable	Third graft: Abundant	Remarks
						aB				hB				aB				
142 d	6	6			7		+			+								Fig 17
113	7	7			120		+			+								
43	7	15	4		7			+		+				+				[illegible] (al)
60	8	15	3		3		+			+				+				[illegible] (al + aB)
72	8	13	5		14		+			+				+				p (al)
62	7	21			25			+		+								[illegible] (al)
137 d	6	21			10			+		+								
136 d	6	29			10			+			+							Fig 19
139 d	6	28			10			+			+							[illegible] (al) the [illegible] of the hB had con[illegible] [illegible] fluorescence
55	9	12	5		13			+			+				+			
90	6	90	7		7				+		+				+			
91	6	90	7		7				+			+				+		
										aBl				aB or hB				
68	7	14	5	3				+		+				+				Fig 18
69	7	14	3	3				+		+				+				[illegible] (al aB aBl)
70	7	14	3	3				+			+				+			pe (al)
71	7	14	3	3				+		+				+				pe (aB + aBl) Fig [illegible]
67	7	21		5	8			+		+				+				p (al + aBl) Fig [illegible]

Explanations d(dexter) after number in which femur the grafts were implanted
[illegible]ections for histological examinations as well
pe(al) periosteum in al

Autogenous fresh bone and autogenous bone preserved in the open air or in normal saline solution at room temperature

In orthopaedic operations where bone transplantations must be employed it is often customary first to remove the bone to be transplanted and then keep it in room temperature either in the open air or in normal saline solution After preparatory measures have been taken the transplant is grafted to its new location This may well take 1 to 2 hours especially in spinal fusion In a survey of patients after spinal fusion for scoliosis at the Orthopaedic Hospital of the Invalid Foudation the suspicion arose that bone tran plants when preserved in the open air may lose a part of their osteogenetic capacity

This question was studied with the method described above in both tetra cycline series The material consists of 34 experiments Six specimens were reserved for histological survey as well All the grafts were implanted without periosteum The material and the results are presented in the table 5

It was found out that one hour s preservation in the open air was enough to change the properties of the bone transplant to such an extent that the bone began to resemble frozen bone (Figs 22 23 25 27 28)

In normal saline solution the bone graft retained the properties found to be characteristic of fresh autogenous bone for a more prolonged period (Fig 29) but a difference began to appear within 2 hours (Fig 26) and after three hours the bone behaved like bone preserved one hour in the open air in comparison with freshly transplanted bone

All tetracycline (Figs 22—29) and histological (Fig 30) preparations in these experiments gave fully uniform results

Comments It was unexpected that bone tissue is so sensitive that one hour s preservation in the open air was enough to make the autogenous bone similar to the frozen bone Dryness lack of oxygen etc are obviously the rea ons for which after 4 weeks the formation of the tetracycline labelled bone and bone tissue containing osteocytes were seen to be scanty in such bone The same reasons probably prevented the formation or influence of some factor stimulating o teogenesis because there was less bone formation in the host bone at the site of such a transplant in comparison with a fresh autograft

No attempt wa made to make any distinction between time intervals of less than one hour of preservation in the open air because many other factors such as air humidity etc may contribute to the time factor in changing the properties of a bone graft

From the practical point of view it seems important that one hour was sufficient to reduce the osteogenetic properties of fresh autogenous bone if preserved

in the open air to the level of those of frozen bone This suggests that in clinical surgery it may be wise to transfer the bone immediately to its final site or if this is impossible at least to preserve it in normal saline solution

In the literature not enough attention has been paid to this question nor have experiments elucidating this matter as far as known been previously made

TABLE 5 — *Autogenous fresh bone and autogenous bone preserved in the open air or in normal saline solution*
Series I (tetracycline injection after grafting)

No of rabbit	Age at transplantation (weeks)	Time of observation (days) (from grafting to last inj.)	Autograft preserved in the open air (hours)	Autograft preserved in saline solution (hours)	Tetracycline fluorescence in the graft: Autogenous fresh graft				Autograft preserved in the open air				Autograft preserved in saline solution				Remarks
					None or minimal	Scanty	Considerable	Abundant	None or minimal	Scanty	Considerable	Abundant	None or minimal	Scanty	Considerable	Abundant	
119	6	15	1			+			+								
65	6	15	2				+		+								Fig 24
66	6	15	2				+		+								
80	6	21	1					+		+							Fig 25
81	6	21	1					+		+							
120	6	22	1			+			+								
121	6	22	1					+		+							
122	6	22	1					+		+							
125	6	22	1				+			+							
105	5	28	1				+			+							
127	6	28	1				+		+								
128	6	28	1				+			+							
140 s	6	28	1				+			+							
140 d	6	28	1							+							a f oz homog aft as th second g ft Scanty fl escenc
93	5	35	1					+		+							
94	5	35	1					+		+							Fig 23
95	5	35	1					+	+								Fig 22
96	5	35	1					+		+							
129	6	41	1					+		+							Fig 30
130	6	41	1					+		+							
63	6	15		2			+							+			Fig 26
64	6	15		2			+							+			
78	6	21		3			+						+				
79	6	21		3			+							+			
102	6	28		1				+							+		
105	6	28		1				+								+	

Continued

Table 5 — Continued

Series II (tetracycline injection prior to grafting)

No of rabbit	Age at transplantation (weeks)	Time of observation (days) (from grafting to killing)	Autograft preserved in the open air (hours)	Autograft preserved in saline solution (hours)	Loss of tetracycline fluorescence												Remarks
					Autogenous fresh graft				Autograft preserved in the open air				Autograft preserved in saline solution				
					None or minimal	Scanty	Considerable	Abundant	None or minimal	Scanty	Considerable	Abundant	None or minimal	Scanty	Considerable	Abundant	
109	5	30	1				+		+								Fig 28
110	5	30	1			+			+								
111	5	42	1					+		+							
112	5	42	1					+		+							Fig 27
114	5	42	1					+		+							
106	5	30		1			+								+		
107	5	42		1				+								+	
108	5	42		1				+								+	Fig 29

Explanations

s(sinister) or d(dexter) after number in which femur the grafts were implanted

sections for histological examinations as well

DISCUSSION

For almost a hundred years experimental studies on bone transplantation have been carried out in various parts of the world. Mice, dogs and especially rabbits have been employed as experimental animals. Bone has been transplanted into soft tissues, into the anterior chamber of the eye and into bony surroundings using widely different techniques. On the basis of such investigations quite contradictory views have been expressed concerning the fate of the cells in transplanted bone tissue. This may partly be due to the diversity of the methods, but it is highly probable that after all the main reason for this controversy has been the lack of adequate methods of demonstrating the fate of transplanted bone. The interpretation of the histological appearance may give rise to differences of opinion. The more unambiguous a method of investigation is, the more reliable are the conclusions. In recent years isotope studies have been successfully employed in studies on bone transplantation. Still simpler than the isotope technique is supravital labelling of bone formation with tetracycline used since 1957 in bone research. As far as is known this is one of the very first times that the tetracycline method has been used in studies of bone transplantation.

With the aid of the yellow fluorescence caused by the tetracycline, the sites of new bone formation may be readily and unambiguously distinguished. Although tetracycline may also be deposited elsewhere, as was stated above, this occurs in such low concentrations that misunderstanding will not arise provided that time interval between the last tetracycline injection and killing of the animal is at least 48 hours. In this case no tetracycline will be seen in the place of resorption and the short-lived fluorescence of inactive surfaces has disappeared (*Milch et al.* 1958, *Harris et al.* 1962, *Hulth* and *Olerud* 1962). Many investigators (among others *Saxén* 1965) have observed that tetracycline has an inhibiting effect on osteogenesis. In the present study tetracycline doses were usually administered at intervals of one week. Therefore the inhibiting effect of tetracycline is hardly of any consequence because the inhibition is reversible and tetracycline will be eliminated in 24 hours (*Saxén*).

The surgical technique employed in the present experimental work is simple. Naturally there are individual differences in new bone formation between

different rabbits but this is of no significance since the differences in osteo genesis were studied in bone transplants grafted into the same femur

Reorganization of bone grafts occurs through resorption of the original graft and formation of new bone Both of these events were studied with tetracycline in a way described on page 25 and complementary pictures of the reorganization of the bone transplant were thus obtained

The present investigation has proved beyond dispute that a fresh autograft possesses the greatest tendency to be reorganized and incorporated as a part of the living skeleton not attained by preserved bone even in a bony environment There were no differences worth mentioning between autogenous frozen bone homogenous frozen bone and autogenous bone preserved in whole blood (Figs 3 6)

In a fresh autograft new bone formation was seen within one week whereas preserved bone began to show some slight osteogenesis only after 3 weeks Reorganization of the fresh autograft progressed quickly (Figs 2 5 7 8 12) Within 3 months (Figs 14 21) the fresh autograft completely resembled the lamellary structure of the host bone whereas in the preserved bone not more yellow tetracycline fluorescence could be seen than after 2 weeks in fresh autogenous bone (Fig 3) New bone formation in the fresh autograft could be so abundant that the transplant grew 2—3 times larger than it was originally (Figs 7 20) and it was impossible to say where the original transplant lay This suggests that the fresh autograft actively participates in the bone formation

Reorganization of the preserved bone occurred very slowly For a long time the reorganization was therefore restricted merely to parts close to the surfaces of the graft Within 3 months the preserved bone retained its shape and never grew larger than it was originally The resorption was more strongly apparent in the preserved bone than in autogenous fresh bone because in the former new bone formation lagged clearly behind

Besides reorganization of the bone graft in these preparations new bone formation could be seen on the surface of the host bone (femur) in the immediate neighbourhood of the transplant The new bone formation origina ting from the host bone had a clear drift towards the fresh autograft (Figs 19 24) In about 5 to 7 weeks the fresh autograft was generally becoming embedded in bone formed by the host bone and obviously also by the graft itself and sometimes the graft could hardly be distinguished from the host bone (Figs 8 10) New bone formation at the site of preserved bone on the other hand occurred mostly slowly and the preserved graft could easily be detached from the host bone even after several weeks

The present investigation also produced evidence to the effect that it made no difference whether bone was preserved in the bone bank for one or several days because it reorganized equally poorly. The time factor however played an important role in the handling of autogenous bone. Keeping it for one hour in the open air at room temperature already meant that the bone decidedly lost its osteogenetic capacity and most closely resembled frozen bone (Fig. 22 25). If preserved in normal saline solution however definite difference in osteogenesis became apparent after 2 hours (Fig. 26) and after 5 hours it was equal to frozen bone. Autogenous bone preserved for 3 to 5 days in the animal own blood at 37 C behaved in the same manner as frozen bone (Fig. 5)

In this study the pieces of ribs utilized always contained also bone marrow. Both tetracycline and histological findings showed early bone formation in the bone marrow of the autogenous fresh graft. The role of the fresh autogenous marrow in reorganization of the transplant is supported by *Burwell's* experiments (1964) with the composite homograft autograft. He found that most of the new bone formed in this kind of composite graft is derived from the autogenous marrow. In his opinion the primary wandering cells (called the intermediate cells by *Trueta* 1963) derived from the littoral cells of the surviving marrow are differentiated into osteoblasts by the osteogenetic substance liberated from the dying bone and marrow tissues of the transplant

The role of the periosteum in osteogenesis emphasized by *Ollier G* and *H Axhausen* and *Laurio* was not systematically studied since this question has been competently dealt with in earlier investigations (*Laurio* 1948). In the present study the general impression has also been that fresh bone transplanted with its periosteum will regenerate more rapidly than if the periosteum is absent. On the other hand it seemed that periosteum covered preserved bone does not undergo osteogenesis any better than when transplanted without the periosteum

What causes the difference between fresh autogenous bone and preserved bone? *It becomes obvious that antibody reaction cannot play any significant role* as apart from homogenous frozen bone only autogenous preserved bone was used. Besides freezing has been found to diminish the antigenic status of the homogenous bone and in the present investigation no differences could be found between autogenous and homogenous frozen bone

When looking for the cause of the more rapid reorganization of a fresh autogenous transplant two questions must be answered

1) Are there in a fresh autograft surviving osteogenic cells?

2) Are factors stimulating bone formation and important to the process of the reorganization of the transplant destroyed during the preservation?

The present series would suggest that freezing destroys the cells in a graft 3 weeks following transplantation the lacunae of frozen bone were still histologically empty nor had any tetracycline incorporation worth mentioning occurred Several previous investigations corroborate these observations and physico chemical incidents in the frozen bone make them understandable Drying lack of oxygen etc on the other hand are obviously the reasons why a bone preserved for one hour in the open air acts like frozen bone

It seems obvious that osteogenic cells survive in a fresh autogenous transplant This is supported by the following observations

- New bone formation could already be seen after one week
- New bone formation did not always appear first in that part of the graft that had been inserted into the burr hole of the femur It could also arise from a part of the transplant separated from the host bone and sometimes even from the interior and not from the outer surface of the graft
- In addition histological findings suggested that some part of the fresh autogenous bone survived after transplantation (see comments page 35)

The idea according to which osteogenic cells survice in a fresh transplant is supported by recent investigations *Ray* and *Sabet* in 1963 using tritiated thymidine and *Arora* and *Laskin* in 1964 using sex chromatin as a cellular label found that in an isograft (naturally also in an autograft) both the cells of the graft and those of the host are capable of taking part in new bone formation Even recent immunological investigations have supported this view (*Chalmers* 1959 *Burwell* and *Gowland* 1961 *Maudsley* and *Harrison* 1963) *Chalmers* found that after implantation into the muscle new bone formation occurs in two phases in fresh homogenous cancellous bone in the early phase new bone is already present on the fourth day and dies out on the eighth day while in the late phase new bone will appear after four weeks albeit in only some transplants According to his interpretation the destruction of the bone formed in the early phase proves that these osteogenic proliferating cells survive in the homograft resulting in acquired immunity in the host In the late phase on the other hand new bone formation starts from the surrounding connective tissue as a result of induction *Chalmers* as well as *Burwell* and *Gowland* made the observation that if the host bone is sensitized to the donor beforehand this will prevent early bone formation in homogenous graft In their opinion this support the view that the new bone formation in the early phase is derived from the cells of the transplant They found that in the fresh autograft this early bone formation is more abundant and progresses without interruption becau e is not immunological reaction to destroy the cells

To the first question whether osteogenic cells are surviving a graft one is thus justified to answer in the affirmative A

question it is obvious that bone degeneration and necrosis [illegible] bone transplantation when blood circulation to the transplant [illegible] This results in the release of biochemical agents which in the [illegible] authors are responsible for the reorganization of the transplant [illegible] agents stimulate surrounding pluripotential cells to form bone [illegible] *Trueta* (1963) such a substance would arise after the death of [illegible] osteocytes and endothelial cells of the graft exerting a stimulating [illegible] upon angioblasts in the vascular system of its environment This leads [illegible] lization of the graft and unless there is an antibody reaction as occurs [illegible] homogenous bone is used the development of osteoblasts from endothelial cells begins

Freezing always causes alterations in the biochemical structure of the bone (*Suber* 1956) So having compared fresh and frozen autogenous and homogenous bone grafts with each other *De Bruyn* and *Kabisch* (1955) found that fresh autogenous bone is definitely more valuable They concluded that freezing destroys the osteogenetic substance They also explained that at the moment of transplantation there are still cells surviving in an autogenous fresh bone that are capable of producing such a substance which induces the mesenchymal cells to form bone Since homogenous fresh bone cannot do this they believed that this substance is partly specific

However attempts upon isolating some osteogenetic substance have not been successful and *Urist* (1965) does not even believe in its existence According to him bone induction is more complex than a simple chemical stimulus and direct cellular response On the basis of *Spemann*s theory of induction he suggests that cellular differentiation occurs by autoinduction proliferating pluripotent ingrowing connective tissue cells interact and produce osteoblasts However the evidences for induction by bone tissue are not beyond dispute and many investigators (*Davis* 1957 *Duthie* 1958 *Bridges* 1959) question its value in osteogenesis

The present investigations demonstrate

— There was no early bone formation in preserved bone such as there was in fresh bone After 3 weeks however the reorganization of preserved bone started but it progressed slowly

— The transplant was also found to exert a definite osteogenetic action on the surface of the host bone There even vivid trabeculation occurred in that area which was not in contact with the transplant and which had not suffered any mechanical damage during transplantation

— It was also found in the experiments that a fresh transplant had a definitely stronger influence upon the trabeculation of the host bone than preserved bone

— The fresh autograft has obviously some osteogenetic effect on preserved bone because new bone formation in the latter almost regularly started in the part that was next to the fresh transplant (Figs 7 25 30)

These observations would suggest that there exists some system stimulating osteogenesis with an effect on the reorganization of the transplant even in the case of preserved bone In addition it is plausible that the preservation of the bone destroys some sensitive factors stimulating osteogenesis This deleterious effect on the autogenous bone is already produced by one hour s preservation in the open air However the nature of the system stimulating osteogenesis is obscure Solution of this question is difficult because obviously osteogenesis is a result from interaction of many biochemical factors

On the basis of the results of the present investigation it is apparent that the rapidity with which immediately transplanted autogenous bone reorganizes as compared with the preserved bone is due to the survival of a part of the grafted bone transplant and to the influence of some easily destructible factors stimulating osteogenesis

Sir Reginald Watson Jones said when speaking of bone grafting at the American College of Surgeon s meeting in San Francisco in 1951 that if he had to perform a bone grafting operation he would require grafts the bone cells of which would fight for him (quoted by *Wilson* 1953) This is exactly what bone transplanted from the donor site without delay does It would not merely serve as a guiding structure but actively participates in the bone formation

SUMMARY

In this experimental work the reorganization of autogenous fresh bone was compared with that of autogenous and homogenous frozen bone and with that of autogenous bone preserved in the open air in normal saline solution or in whole blood after free transplantation Attention was also paid to the role of the time factor in reorganization

The property of tetracycline to form a deposit in newly formed bone and to produce yellow fluorescence in ultraviolet light was utilized in the examination of reorganization The study was performed mainly on young rabbits Ribs were used as transplants which were implanted in the femur (Fig 1 page 20) The material comprises 118 rabbits (see page 19) The rabbits were killed 8—90 days after operation

By the tetracycline method it was possible to study both components of reorganization the formation of new bone and the resorption of the original transplanted bone New bone formed after transplantation (apposition) was made visible by injecting tetracycline in rabbits at intervals of about one week after the bone grafting Resorption could be estimated by observing how the rib labelled with tetracycline before grafting lost its yellow fluorescence when it was serving as a transplant In addition histological examination was used as a parallel method The results obtained with both methods are in conformity with each other

In the experiments performed the difference in osteogenetic capacity between autogenous fresh bone and any other kind of bone graft proved to be very great (Figs 2 a 24) First fresh autogenous bone became reorganized decidedly more rapidly and second new bone was also formed from the host bed in greater amounts at the site of the fresh transplant than when preserved bone was used

There were no differences worth mentioning between homogenous and autogenous frozen bone and autogenous bone preserved in whole blood (Figs 3 6)

It could not be shown here that the time of preservation of the bone in a frozen state could have any essential effect on its capacity of reorganization

Autogenous bone preserved in the open air at room temperature for about one hour lost its osteogenetic properties to the extent that it almost resembled

fro en bone (Figs 22 23 25) On the other hand if bone was preserved in normal saline solution this degradation did not occur until after about 2 hours (Figs 26 29)

The difference between fresh and preserved autogenous bone may be due to the fact that living o teogenic cells even ome osteocytes survive in fresh bone after transplantation A fresh autograft would thus not merely serve as a guiding structure but actively participates in the bone formation while at same time it gives rise to stronger bone formation from the host bone than preserved bone The possibility cannot be excluded that the tranplant contains or develops some inductive substance which is rapidly destroyed or whose development is readily inhibited

The observation that one hour s preservation in the open air in the experiments resulted in diminished osteogenesis of the bone might be significant from the point of view of clinical practice

The main focus of this study has been to try to elucidate the question whether an immediately transplanted autogenous bone graft is more quickly and completely incorporated into the skeleton than a preserved autogenous or homogenous graft The experiments strongly support a preference for immediate transplantation of autogenous bone

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FIGURES

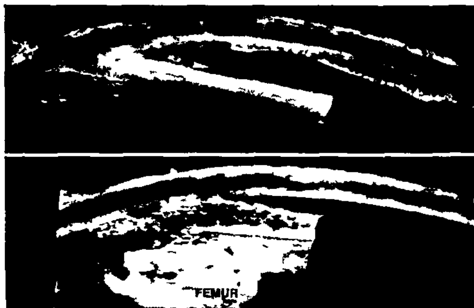


FIG 4 — (spec 26) 10 days from grafting to last tetracycline injection Longitudinal section The frozen autograft aB displays bluish dense autofluorescence In the fresh autograft aF there appears yellow fluorescence (apposition) mostly in that part which is not implanted in the host bone Note that the new bone formation seems to begin in the central part of the upper corticalis

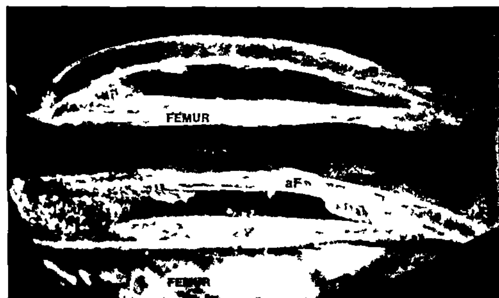


FIG 5 — (spec 44) 15 days from grafting to last tetracycline injection Longitudinal section The autogenous frozen bone aB exhibits minimal tetracycline fluorescence outside the site of implantation The fresh autograft aF is extensively [illegible] especially in the distal part At both ends of the transplant there is al[illegible] bone formation derived from the host bone This bone formation has [illegible] in fusion with the transplant

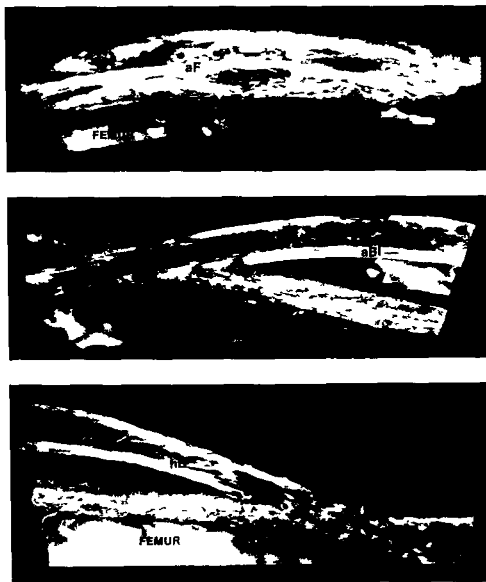


FIG 6 — *(spec 67) 3 weeks from grafting to last tetracycline injection Longitudinal section In the homograft hB and autograft preserved in blood aBl there is reorganization only at the site of implantation The fresh autograft aF has yellow fluorescence in most parts of the transplant especially in the upper corticalis The bone formation derived from the host bone is almost non existent in preserved bones but in the fresh graft it has reached the surface of the transplant and at the site of implantation the obtuse angle between the host bone and the graft is filled up with new bone (arrow)*

FIGS 7 a b c d and e — *(spec 57) 6 weeks from grafting to last tetracycline injection*

— a *Front view of the femur with the grafts The frozen autograft aB and the autogenous bone aP preserved in Palavit are clearly seen The fresh autograft aF between both preserved bones is hardly discernible from the host bone*

— b *Longitudinal section of the fresh autograft aF This proximal part is almost completely incorporated into the host bone*

— c and d *Longitudinal section In aB and in aP reorganization is found only at the site of implantation Yellow colour indicated by the arrows is reflected from the surface of the fresh transplant At the site of these transplants there is only very little new bone formation derived from the host bone*

— e *Cross section along the dotted line of the distal part of the transplants (see fig a) The fresh autograft is found to be completely reorganized Because of the new bone forming the transplant has lost its form to the extent that it is hard to say what part of it represents the original transplant Tetracycline incorporation in the preserved bones is seen mainly in the part adjacent to the fresh transplant*

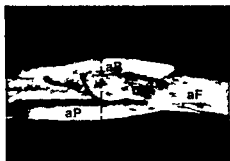


FIG 7a

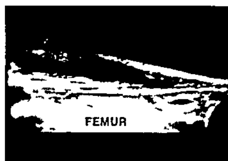


FIG 7b

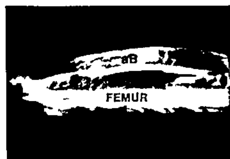


FIG 7c

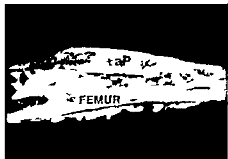


FIG 7d



FIG 7e

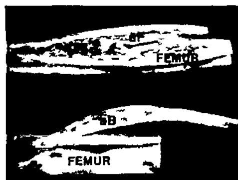


FIG 8



FIG 9

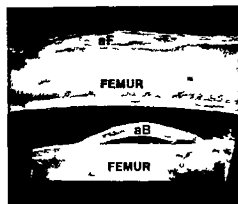


FIG 10



FIG 11

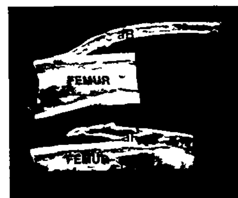


FIG 12

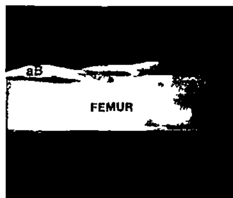


FIG 13

FIG 8 — *(spec 23) 4 month from grafting to last tetracycline injection The fresh autograft aF is almost incorporated in the host bone The autogenous frozen bone aB looks as if it had been recently grafted*

FIG 9 — *(spec 17) 4 weeks from grafting to last tetracycline injection The fresh autograft aF has started to reorganize and peculiarly new bone is present mostly in that part of the transplant which is not implanted in the host bone The frozen autograft aB looks as if it had been recently transplanted*

FIG 10 — *(spec 10) 5 weeks from grafting to last tetracycline injection The fresh autograft aF is completely incorporated into the host bone The frozen autograft aB exhibits scanty yellow fluorescence*

FIG 11 — *(spec 32 s) 5 weeks from grafting to last tetracycline injection The frozen autograft aB displays only bluish autofluorescence In the fresh autograft aF there is lively resorption and apposition The new bone derived from the host bone at the site of implantation has started to surround the transplant like a cuff*

FIG 12 — *(spec 50) 2 months from grafting to last tetracycline injection In the frozen autograft aB there is scanty new bone The fresh autograft aF is fully reorganized and only the tip of it is not incorporated into the host bone*

FIG 13 — *(spec 21) 3 months from grafting to last tetracycline injection Side view Both the autografts are clearly discernible The fresh graft aF has lost its original shape It exhibits abundant yellow fluorescence which is almost lacking from the frozen bone aB Only scanty new bone formation at the transplants in the host bone*



FIG 14 — *(spec 88) 3 months from grafting to last tetracycline injection Gross section The autogenous frozen graft aB has only scanty tetracycline incorporation and its contour is well defined The fresh autograft aF has undergone complete lamellary reorganization and at this site is incorporated in the host bone Note the strong new bone formation in the host bone The surface of the femur is not seen in the picture*

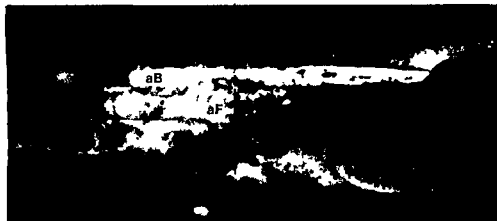


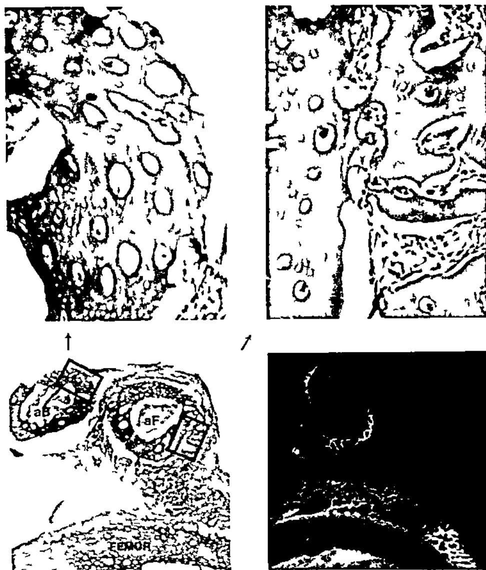
FIG 15 a

FIG 15 b

FIGS 15 a and b — *(spec 83) 3 weeks from grafting to killing Tetracycline injection prior to grafting*

— a *Front view of the femur with the transplants The frozen autograft aB has retained its yellow tetracycline fluorescence (minimal resorption) The fresh autograft aF excluding the distal part has lost its yellow fluorescence through resorption The arrow indicates the proximal end of the fresh autograft*

— b *Cross section along the dotted line (see fig a) In aB the outline is only slightly broken and the loss of tetracycline has hardly started In aF reorganization has progressed to a great extent and it is difficult to discern it from the bone formation derived from the host bone*



The squared areas in the picture of the grafts are magnified in the figures above as pointed by the arrows

FIG 16 — *(spec 135 s) 10 days from grafting to killing Immature bone trabeculae are encountered on the external surface of the fresh autograft aF Nucleus-containing lacunae of normal bone are seen especially in the superficial parts of the graft In tetracycline ground section (prepared from the site near histological section) there is yellow fluorescence in the area of immature trabeculae but not in that of normal bone tissue of the graft The fro en autograft aB is necrotic all over New-bone formation on the host bone*

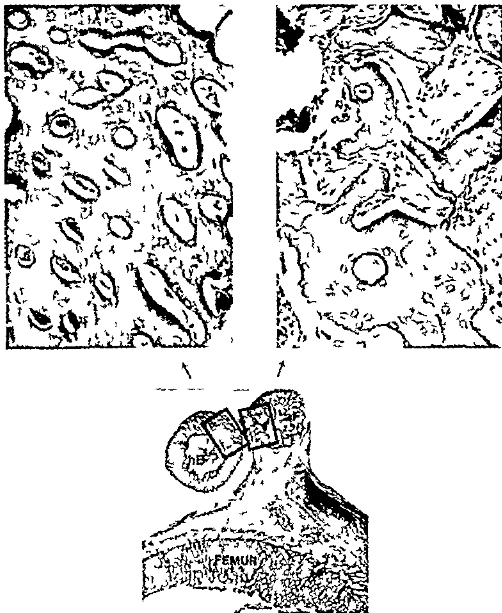


FIG 17 — (spec 142 d) 9 days from grafting to killing All lacunae of the homogenous frozen bone hB are empty Islands resembling immature bone and nucleus containing lacunae of normal bone are found in the fresh autograft aF Abundant osteoblasts indicate active osteogenesis Note the numerous cells in autogenous graft

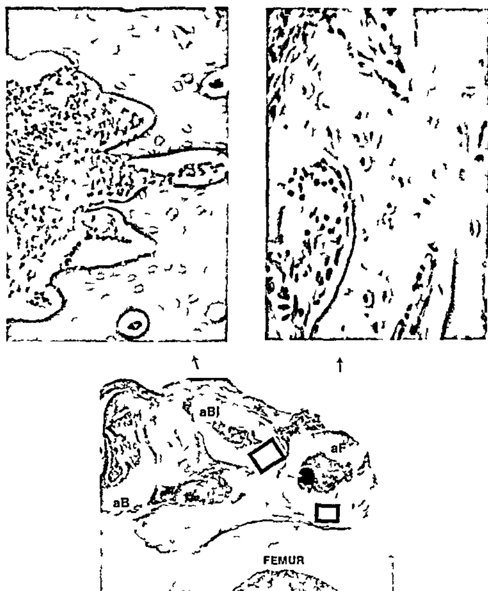


FIG 18 — *(spec 68) 16 days from grafting to killing The autograft aBl preserved in blood and the fro en autograft aB are necrotic Especially in that part of the fresh auto graft aF which is close to the host bone the immature bone trabeculae and numerous osteoblasts indicate intensive reorgani ation Cf fig 3*



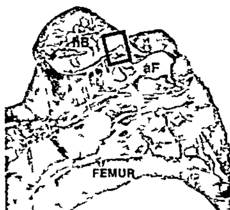




FIG 19 — *(spec 136 d) 1 month from grafting to killing In histological section the transplants hai e become fused The ıtal bone tissue of the fresh autograft aF ends u ith a sharp line of demarcation against the necrotic tissue of the fro en homograft hB Some nucleus-containing lacunae in the fro en bone are seen mainl in the part ad jacent to the fresh transplant In tetraci cline section (prepared from the site near the histological section) some spots of ellou fluorescence are found in the fro en graft In the fresh graft the ellou fluo escence indicates considerable reorgani ation Neu bone formation from host bone has a drift tou ards the fresh autograft and is so abundant a separate cai ity has dei eloped*

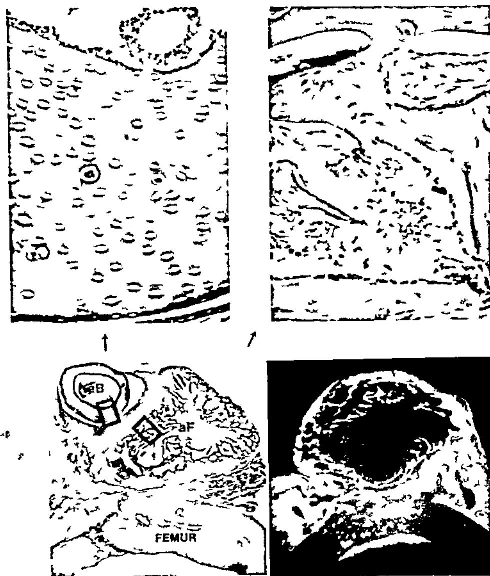


FIG 20 — (spec 134) 21 days from grafting to killing The fresh autograft aF has lost its shape and grown much larger than it was originally Its bone tissue is vital all over and signs of active osteogenesis are seen at the bone margins The frozen autograft aB was rejected alongside the fresh autograft Its lacunae are empty Trabeculation in the host bone is seen near the fresh autograft In tetracycline ground section (prepared from a site near the histological section) yellow fluorescence indicates intense new bone formation in the fresh graft aF The strong trabeculae cement the transplant to the host bone The frozen graft aB exhibits only minimal tetracycline fluorescence Adult rabbit



FIG 21 – *(spec 131 s) 3 months from grafting to killing The fresh autograft aF has become denser and lost its original form and si e Its structure resembles the la nel lary structure of the host bone The fro en autograft aB is porous but there are only scanty nucleus containing lacuna*



FIG 22 — (spec 95) 5 weeks from grafting to last tetracycline injection Front view of the femur with the transplants The autograft aD preserved for one hour in the open air is as if recently implanted The fresh autograft aF excluding the distal end is fully reorganized



FIG 23 — (spec 94) 5 weeks from grafting to last tetracycline injection The fresh autograft aF has undergone lamellary reorganization The autograft aD preserved for one hour in the open air displays tetracycline incorporation in the part adjacent to the fresh graft



FIG 21 — (spec 131 s) 3 months from grafting to killing The fresh autograft aF has become denser and lost its original form and si e Its structure resembles the la nel lary structure of the host bone The fro en autograft aB is porous but there are only scanty nucleus containing lacunae

FIG 26 — (spec (1) 15 days from grafting to la t tetrac line inje tion The f sh autograft aI and the autograft aS preserved for two hours in saline soluti n h e no great differences although in the fresh graft reorgani ation has progres ed somewhat further



FIG 27 — (spec 112) (weeks from grafting to killing Tetracycline injection prior to grafting Side view The autograf aD preserved for one hour in the open air has retained considerable yellow tetracycline fluorescence (scanty resorption) The fresh autograft aF is completely incorporated in the host bone Small yellow points on its surface indicate the site where the transplant is lying



FIG 28 — *(spec 109) 1 month from grafting to killing Tetracycline injection prior to grafting Cross section The autograft aD preserved for one hour in the open air has kept intense yellow tetracycline fluorescence (minimal reorganization) The fresh autograft shows only some spots of yellow fluorescence (considerable resorption of the original tetracycline-labelled bone)*



FIG 29 — *(spec 108) 6 weeks from grafting to killing Tetracycline injection prior to grafting Two cross sections The fresh autograft aF and the autograft aS preserved for one hour in saline solution are incorporated in the host bone Only some tetracycline spots left No difference in reorganization*

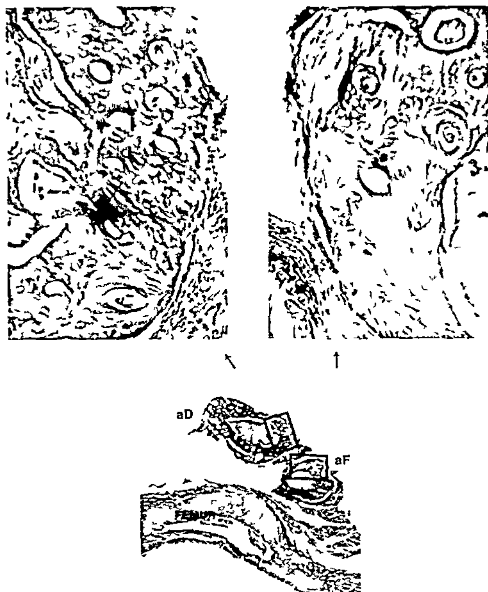


FIG 50 — (spec 129) 43 days from grafting to killing The fresh autograft has become denser and is definitely smaller in size than originally Most of its lacunae contain a nucleus and its structure resembles the lamellary structure of the host bone The autograft aD preserved for one hour in the open air is porous but nucleus containing lacunae are not seen anywhere else than in the part adjacent to the fresh graft and largely in the form of islands on the medullary aspect

INTRAVITAL MEASUREMENTS DURING INSTRUMENTAL CORRECTION OF IDIOPATHIC SCOLIOSIS

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by

THEODORE R WAUGH

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Munksgaard Copenhagen 1966



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Foreword

In 1958 on joining the staff of the New York Orthopedic Hospital, it was my good fortune to become associated with several men who were deeply interested in the problems of scoliosis and spine fusion in fact an interest that has been maintained since the original work of Hibbs with this disease

This investigation has consisted of two parts the first of which the clinical began when Professor Frank E Stinchfield made me responsible for the Scoliosis Service at Columbia University With a background of over 2 500 surgically treated patients with spinal deformity, the majority of whom have been carefully followed it was believed that the New York Orthopaedic Hospital could provide valid conclusions about the efficacy of existing treatment

In 1965 the second phase the experimental, was begun in the Biomechanics Laboratory of the University of Gothenburg Professor Carl Hirsch has provided the facilities encouragement, and personal guidance which enabled this work to be carried out

Any study of this nature depends upon the cooperation and assistance of many people I would like to thank the staff at the Orthopedic Clinic for their suggestions and cooperation

During the execution of particular phases of this project, technical problems arose which required the assistance of specialists from other institutions I would particularly like to thank Engineers Soren Rolandsson and Hans Åkesson of the AB Atomenergi in Studsvik, Sweden Lector Esbjorn Carlstrom the University of Gothenburg Tek Lic Lars Sonnerup, Chalmers Tekniska Hogskola and Engineer Nils Årthun Department of Bacteriology of the University of Gothenburg for their valuable assistance

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Contents

In Cobb's (1948) etiological classification of scoliosis, approximately 90 % of cases fall within the idiopathic category. One might assume, therefore, that the pathogenesis of the remaining 10 % was clearly established; however, such is not the case. Until recently, the second largest category within the classification has been the paralytic or neurogenic group.

Muscle paralysis

In 1941, Colonna and Vom Saal attempted to correlate muscle paralysis with type of curvature. It is well recognized that there were many curvatures that they were unable to correlate with any specific paralysis. James (1956), in a careful review of his cases, refuted some of the conclusions of Colonna and Vom Saal. Arm and leg muscle paralysis were not related to the production of scoliosis, nor were the mid-line muscles such as the erector spinae and the anterior abdominals. In a significant number of cases, however, it was apparent that the intercostals, the lateral abdominals and the latissimus dorsi were weak on the convexity. In regard to specific curve patterns, James found that intercostal muscle weakness, although this is a difficult assessment, was associated with thoracic curves in a significant number of cases. Thoracolumbar curves were found with convex lateral abdominal weakness and it was his feeling that gravitational forces were important in the development of this curve. In lumbar curvature, apparently the important muscles were the lateral abdominal flexors (quadratus lumborum, the lateral portion of the anterior abdominal muscles and possibly the latissimus dorsi). Michele (1962) has stressed the importance of the iliopsoas. With regard to mid line muscle paralysis, James agreed with Steindler (1929) that anteroposterior rather than lateral curves developed from this weakness. Garrett, Perry and Nickel (1961) also found in their series of cases a correlation between thoracic curves and intercostal muscle weakness, the convexity being towards the weaker side.

When scoliosis develops following poliomyelitis, it may be easier to understand the development of spinal curvature, but the fact that a perfectly clear cut relationship does not exist seems important. This might be explained by the difficulties of muscle grading, the generalization of paralysis, or perhaps it merely reflects the underlying problems of scoliosis in general. Risser (1964) and Gruca (1958, 62, 63) have advanced a muscle weakness theory for the pathogenesis of idiopathic scoliosis. It is Gruca's belief, in agreement with Andry (1743), Movshovich (1960) and others, that idiopathic scoliosis is caused by impaired equilibrium of muscular

activity at the level of the initial curvature On the basis of his investigations he has concluded that the musculature on the convex side of the curve is weakened and degenerated and there is increased tension on the concave side He has illustrated this theory with a model of the spine utilizing rubber bands as muscular motors Zuk (1962) in studying the electrical activity of the back musculature found greater activity on the convex side It is his impression however that increased electrical activity may be a sign that a muscle is reaching the limit of its power and thereby represents weakness rather than strength On this basis he also postulates that scoliosis is due to muscle imbalance the weaker muscles being on the convex side of the curve and that the increased electrical activity on the convex side represents the body s attempt to compensate for the curvature In subsequent studies Zuk (1965) noted signs of fatigue on the convex side of progressing curves whereas in fixed curves he found increased tone

Liszka (1961) performed an interesting series of experiments on young rabbits with segmental elimination of spinal cord function By unilateral transection of multiple spinal roots scoliosis was produced which was convex to the operated side He also noted as a result thereof some affect on the growth of the convex vertebral bodies It was his impression that idiopathic scoliosis was caused by a primary injury to the cord It is of interest that Riddle and Roaf (1955) in contrast with these findings found dorsal concave muscular weakness associated with spinal curvature. Gorynski and Bojkowa (1957) in examining specimens obtained at surgery, have found histological evidence of degenerative changes in the muscle on the convex side of idiopathic curves Bisgard (1935) Schwartzmann and Miles (1945) produced varying degrees of scoliosis experimentally by muscle excision but in many cases the curves corrected spontaneously or were trivial

From these conflicting reports in the literature it may be concluded that damage to the neuromuscular unit may be responsible for some types of scoliosis but whether such is the case for the idiopathic group as a whole does not appear to be established In all probability some cases in the idiopathic grouping may be attributable to hidden central nervous system disease or damage but that such could be the general case seems unlikely

The costotransverse ligaments

Wenger (1951) observed that the post thoracoplasty development of scoliosis depended upon the intactness of the transverse processes and the various ligaments attached thereto In the treatment of existing scoliosis by transversectomy he noted an immediate degree of correction that persisted Lagenskiold and Michelsson (1959 61, 62 63) in attempting to produce

spinal deformities in animals comparable to scoliosis in man, found that resection of the deep back musculature, transection of the intertransverse ligaments, and, transection of the ribs lateral to the tubercles caused no scoliosis, whereas resection of the dorsal ends of the ribs, transection of the ligaments of the heads of the ribs, transection of both external and internal intercostal muscles, radical hemilaminectomy, transection of the transverse ligament, and in the lumbar area, transection of all the muscles and ligaments attached to the arches and transverse processes consistently cause scoliosis It was their impression that resection of the dorsal ends of the ribs caused the most severe functional and structural scoliosis As a result of their operative procedures, they noted the development of rotation with wedging vertebral deformity and "rigid curves The apical vertebrae were higher on the convex side with decreased size of the concave arch They also noted displacement of intervertebral discs towards the convexity with uneven and irregular endochondral ossification on the concavity In reviewing this data, they concluded that the significant factor amongst the thoracic operative procedures was section of the posterior costotransverse ligaments An interesting finding in this regard was the disappearance of the scoliosis under deep anesthesia or with death of the animal This they attributed to the role of the muscles in the development of the deformity, particularly the intercostals In applying their findings to idiopathic scoliosis in man section of the concave costotransverse ligaments was undertaken to produce a counter-scoliosis It was their preliminary impression that this procedure resulted in correction of the existing deformity Flinchum (1963) also reported good results from concave rib resections, however, in cases to be reported, the author has not been able to duplicate these results Lindahl and Raeder (1962), following a mechanical analysis of the forces involved in idiopathic scoliosis determined that the transverse processes acted as tie points which might be lengthened on the convex side and shortened on the concave to produce deformity It was assumed that the intertransverse ligaments and muscles might be important in the production or maintenance of deformity Acting upon this hypothesis, they, as did Wenger resected concave transverse processes, however in a subsequent report (1963) Lindahl stated that this surgical procedure had apparently not influenced the natural course of the disease

The vertebrae

Knutsson (1961) has shown that growth from the superior and inferior surfaces of the vertebral body are equal Bick (1961) remarked that the superior and inferior "epiphyses are wrongly termed because of the

absence of an ossification nucleus He prefers the expression "vertebral growth plate , and as the vertebral rings add nothing to the growth of the vertebral body they should more correctly be called "traction apophyses He quotes the Hueter von-Volkmann law the affect of pressure and traction on growth plates producing asymmetric expansion as an appealing concept for scoliosis Bisgard and Musselman (1940) believe that unilateral growth disturbances are either totally responsible or at least contributory to the development and progression of idiopathic scoliosis They have said that wedge-shaped vertebrae could not develop as a result of compression, and for substantiation cite Wolff s law, thereby reraising an old controversy They believed it more probable that abnormal pressure causes wedging by retarding growth Arkin (1949), discussing the mechanism for structural changes in scoliosis, quoted the Research Com mittee of the American Orthopedic Association (1941) the majority of the members at that time, believing that scoliosis was the result of a disturbance in the growth plate He calculated the pressure on the concave side of the disc as being approximately six to seven times the super incumbent body weight Arkin and Simon (1950) reported their experi mental work producing scoliosis by the implantation of radon seeds, and Arkin Pack, Ransohoff and Simon (1950) and others have reported clinical cases of radiation induced scoliosis Katzman and Waugh (1966) in reporting a large long term follow up study of children treated for tumors by radiation therapy found 28 survivors 23 of whom showed alteration of the vertebral bodies In the latter part of the first year following radiotherapy subcortical lucent zones appeared parallel to the epiphysial plates which progressed to growth arrest lines This gave the configuration of a "bone-within-a bone' as the growth arrest lines were incorporated within the growing vertebral bodies It was our impression that this phenomenon represented an arrest of endochondral ossification of the vertebral bodies and that the size of the "bone-within a bone correspon-ded closely to the size of the vertebral body at the time of the original therapy As growth continued but in a distorted manner the bodies became diminished in vertical height and developed irregularities or scalloping of their superior and inferior surfaces Often the final changes were similar to those seen in Cretinism, Morquio s or Hurler s disease Twenty patients were noted to have scoliosis The curves that developed were all concave toward the side of the tumor, provided there was no known neoplastic invasion of bone Three of these curves measured 40 degrees or more by the Ferguson (1939) method It was believed that dosage levels were related to the severity of the changes observed Tumor dosages greater than 2000 R usually produced skeletal changes in these

growing children No critical dosage level has been observed in humans below which radiation changes in bone are not seen and yet the basic malignant disease was cured The time necessary for development of the radiation changes implied cure of the original disease

With the appreciation that injury to a vertebral growth plate can interfere with normal growth, and when predominantly unilateral, produce scoliosis Arkin and Katz (1956) concluded that pressure inhibited growth, but not by an all-or none law They believe there was no sign of a threshold below which pressure was ineffective A growing epiphysis subject to stress yields to that stress Pressure parallel to the direction of growth inhibited such growth and pressure perpendicular to the direction of growth deflected growth causing lateral or spiral displacement As an assessment of the magnitude of forces involved, they cited the breaking tests of staples used for a Blount (1949) epiphysial arrest They assumed that even gravitational pressure had an inhibitory affect on the growth of bone Stilwell (1962) in a series of muscle resection experiments produced vertebral angulation and rotation by creating unopposed forces In 1939, Haas produced scoliosis in dogs by a unilateral injury to the epiphysis, and he suggested the possibility of using this as a corrective procedure. Nachlas and Borden (1951) caused scoliosis in dogs by clamping vertebrae and then corrected this scoliosis by a similar procedure on the convex side of the curve

With regard to the therapeutic applications of the principle of compensatory growth arrest the results have been only variably successful Smith, Von Lackum and Wylie (1954) were unsuccessful in attempts to staple the vertebral growth plates Le Messurier (1951) found that unilateral epiphysial destruction produced no alteration in the progression of the curve and Moore (1951) stapled the transverse processes without success More recently, Mc Carroll and Costen (1960) attempted surgical epiphysial arrest with inlayed bone grafts on the convex side In this connection however it must be recalled, that the situation at the intervertebral joint is considerably different from the epiphysial plate of a long bone and this may explain some of the failures Roaf (1963), however, has, on the basis of 189 cases recommended his technique of growth arrest

Somerville (1952) believed that the deformity of scoliosis is attributable to a relative failure of growth of the posterior elements which in turn produced lordosis rotation and lateral flexion By cauterizing the vertebral arches of rabbits he produced some degree of scoliosis Wittebol (1956) performed similar experiments in dogs and pigs and believed he had refuted the theory of lateral deviation being a result of unilateral predominance in growth of one or several epiphysial plates Ottander (1963),

on the suggestion of Knutsson (1963, 66) in a series of experiments produced some scoliosis, which he attributed to asymmetrical growth of the neuro central junction

Bick Barash and Lehman (1958) drew reattention to the role of the disc by describing two cases of congenital scoliosis, one of which demonstrated concave annular compression and the other definite displacement of the disc to the convex side Perey and Rydman (1962) and Perey (1963) performed discography at the apex of three curves and found asymmetric positioning of the nucleus In two patient this was convex and in one concave

Farkas (1954) in an extensive pathological and radiographic study of scoliotic spines noted vertebral body channels which he assumed to be the predisposing cause and considered weight bearing the exciting or mechanical cause of idiopathic scoliosis He believed the basic pathological process involved separation of the epiphysial rings and vertebral cortex from the interior of the vertebral body which was probably attributable to atrophy

Under unusual circumstances such as seen in radiation induced scoliosis it is obvious that unilateral epiphysial injury may produce a deformity that in many respects, resembles idiopathic scoliosis, it seems unlikely that the pathological changes in the individual vertebrae are the primary cause of the deformity More likely these changes are the result of abnormal pressure considerations from outside the vertebral column Support for this impression is furnished by the work of Arkin (1964) who was able to overcorrect the deformity of idiopathic scoliosis by prolonged recumbency only to have it redevelop on assuming the erect position

Forces

Steindler (1929) Michele (1962) and others have approached scoliosis by a mechanical analysis A column has been described as a compression member which tends to fail because of unstable equilibrium In general the distinguishing characteristic of a column is its slenderness which is the ratio of the length to the radius of gyration, the latter being with respect to the centroidal axis, about which the column tends to bend As the load on a column increases, the column shortens in accordance with Hooke s or some other physical law and remains in stable equilibrium If however some initial crookedness or eccentricity is present bending begins immediately For initially straight columns as the load is increased, the column remains straight until a certain value called the critical load is exceeded whereupon the column is in a condition of unstable equili

brium Under these circumstances, minor extraneous factors will cause the column to buckle This problem is greatly aggravated by the fact that no warning of this condition is present and hence, failures are nearly always unexpected According to Euler s formula, the critical load depends upon the fourth power of the radius The end conditions modify the formula In general the vertebral column is looked upon as having one end fixed and one end free The deflection curve of this end condition encompasses *the upper 0 707 of the length, whereas with both ends fixed, the deflection* curve involves only the middle half With an axially loaded column there is no bending and the stresses are uniformly distributed over the area of the cross section However with eccentric loading a tendency is produced for column bending With a long column the stress on one side may *become tensile instead of compressive According to the principle of the* middle third the critical eccentricity is only one-sixth of the diameter (Shigley 1963 Parker 1961)

Steindler and Michele have noted there are several situations present in the human spine that prevent anything but a casual analogy to an ideal column *The spine is in fact a pyramid the end conditions are* difficult to establish natural curvatures exist the muscles and ligaments function as ties and the spine is not simple but segmented Lucas and Bresler (1961) have calculated the critical load of a segmented column composed of alternating rigid and elastic elements At the statistically most common apical level of thorasic scoliosis the superincumbent body weight according to Crawford (1965) is about 25 % and interpolating Ruff s (1950) lumbar figures about 40 % of the total body weight Morris Lucas, Bresler (1961) and others by manometric measurement have ascertained the thorax and abdomen to absorb about 50 % of this superincumbent weight From these considerations it might be postulated that the force on the apical vertebra of an adolescent scoliotic might be of the order of 7 to 10 kg With well established curvature Arkin (1949) has calculated compressial forces on the concave side of the epiphysis of up to 14 times this magnitude Using Nachemson s formula for lumbar disks *the apical load would be 57 kg with upright standing (1966)*

The rotational element of scoliosis prompted Lovett in 1902 to state "In the attempt to solve this problem a very large amount of literature has accumulated without obvious practical result He refuted Meyer s (1866) theory of two columns with different elasticity based upon examination *of specimens He concluded* that side-bending and torsion were compound movements and could not be disassociated and that the column of vertebral bodies was the determining factor and not the articular processes This theory has in general prevailed until the present time Many authors

besides Lovett have resorted to models to explain rotation (Risser 1957 Lindahl and Raeder 1962 Arkin 1950 Tidestrom 1958 and others)

Steindler (1929) considered that rotation of the vertebral bodies to the concave side is not the expression of a natural tendency but rather the result of muscular effort Michele has shown in lumbar curves that rotation may be due to the unbalance pull of the iliopsoas Arkin (1950) believed there were two factors in scoliotic rotation one the tendency of muscles and ligaments to describe a straight line and the other the wedge shape of the vertebral bodies Roaf (1958) believes that scoliosis may be explained on the basis of a primary rotation deformity and has stressed the component of lordosis In the presence of an established deformity the long fibers of the erector spinae muscle tend to increase the deformity In a straight spine this muscular pull is opposed by gravity but in the presence of scoliosis gravity serves to reinforce the deforming action of the long spinal musculature Roaf (1958) has also emphasized the role of rib pressure Because of the axis of rotation of the thoracic spine relative to the attachment of the ribs intercostal muscle action will tend to increase the deformity of established curves Lindahl and Raeder (1962) noted that the deformation in scoliosis could not be produced by acute or physiological movements of the spine They also pointed out that in the upper part of a curve the rotational relationship of the inferior to the superior vertebra is clockwise while in the lower half of the curve the relationship is anti-clockwise They believed that rotation in scoliosis was dependent upon the assumption of a larger radius of curvature by the intertransverse ligaments the transverse processes functioning as cross trees or spacers

Gravity has been generally accepted since earliest times to be an important pathogenic factor in the production of scoliosis The most conservative of treatment for the disease has been bedrest which Cobb (1949) stated he had found to be very effective in preventing progression The importance of gravity in the development of scoliosis in man has been reinforced by the absence of the deformity in quadrupeds except in unusual or experimental circumstances

Because of the mechanical design of the human vertebral column a precarious equilibrium must exist that depends upon extraneous factors for its stability Relatively small unbalanced forces could be sufficient to produce significant deformation (Fiess 1907)

Although Roaf (1958) has discussed the action of the ribs in producing a force couple to increase an existing deformity few have concerned themselves with this facet of the problem The ribs have two axes of motion the one elevation about the vertebral fulcrum and the other, rotation about the sternovertebral axis It is of interest that elevation of the anterior

ends of the seventh to tenth ribs is associated with posterior motion of the sternum, while elevation of the sixth thoracic and above is associated with forward motion of the sternum, the movement occurring at the manubriosternal joint With quiet respiration (below 50 liters per minute), the diaphragm, inferior intercostals and occasionally the scalene muscles are active However quiet expiration depends on the elasticity or compliance of the lung, which is known to be abnormal in scoliosis (Gardner, Gray and O Rahilly 1960) In studying vertebral rotation, Rolander (1966) observed that the average height of the disc increased when horizontal torque was applied and the increase was approximately proportional to the degree of rotation This he attributed to the helicoidal arrangement of the fibers in the annulus described by Horton (1958) and Galante and Hirsch (1966) It is possible that the reverse may also be true and lateral deviation might generate a horizontal torque, which would in turn explain at least some of the rotation about the vertical axis

HEREDITY

Several case reports exist in the orthopedic literature of scoliosis in identical twins Generally speaking these curves have been similar but not always indentical Codorniu (1958) described uniovular twins, both of whom had thoracic curves the one measuring 55 degrees and the other 42 Esteve (1958) reported uniovular twins with thoracic curvatures one of which measured 46 degrees and the other 58 In the latter case the roentgenograms show a fairly large lumbar curve which raises the question of a double primary Murdoch (1959) reported additional twins with idiopathic right thoracic curves measuring 55 and 46 degrees He stated that all previously reported cases had been in girls However, Wiest (1954) had presented a clinical and electromyographic study of the paravertebral musculature in uniovular twin boys one of whom had idiopathic scoliosis The curve in this 12 year old was left thoracic with its apex at the seventh or eighth dorsal vertebra The electromyographic studies, showed hypertonic activity at the level of the apex on the right side of the twin with scoliosis Hull (1961) subsequently reported scoliosis in 15 year old binovular twin girls In this family there were five other siblings with one other pair of binovular twins none of whom had scoliosis Molski (1957) found 16 families in Poland of which 38 members had scoliosis Wright and Niebauer (1956) in a study of the association of congenital heart disease with scoliosis found that out of 422 cases of congenital heart disease 5 5 % had a scoliotic deformity which exceeded 10 degrees In those patients over 14 years of age the incidence of scoliosis was 19 % as compared with a controlled incidence of 6 % In no case was the scoliosis related to cardiac

surgery or cyanosis It was their impression that this increased incidence was statistically significant

Gilly Stagnara Frederich Dalloz Robert and Goldblatt (1963) in studying the medical aspects of structural scoliosis in children found that 21 % *of their cases had a family history of the disease They* and James and Wynne Davies (1965) have concluded that the inheritance of idiopathic scoliosis shows aspects of dominant inheritance rather than being multifactorial

These reports suggest a definite hereditary basis but it is interesting that Anders (1965) was unable to demonstrate any chromosomal abnormality in 11 patients with idiopathic scoliosis With future technical refinements however it may be possible to do so

METABOLISM

Kiepurska (1957) *performed various biochemical studies on 50 children* with idiopathic or dystonic scoliosis The children varied in age from 4 to 14 years He found that the calcium phosphorus alkaline phosphatase blood sugar ketonic compounds and alkali reserve differences obtained were insignificant when subjected to statistical analysis Similarly Fiala and Jadrny (1962) confirmed normal values for calcium phosphorus and alkaline phosphatase They also found that the cholesterol creatine and ketosteroids were within normal limits

Stearns Chen McKinley and Ponseti (1955) also found calcium and phosphorus values to be normal However investigating the metabolism of protein *they noted a definite negative balance They found that scoliotic* children required high protein diets in order to retain sufficient nitrogen for normal growth and that in all probability, the normal diets of these children did not contain this amount of protein The negative balance was manifest by increased excretion of urea nitrogen In addition they noted increased excretion of taurine and cysteic acid and/or methionine sulphoxide This represented a significantly high loss of sulphur containing amino acid derivatives Electrophoretic studies of serum amino acids in five of the author s scoliotic patients failed to indicate any significant abnormality (1962) This is in keeping with the findings of Ponseti (1966) Glauber Fernbach Massanyi and Medgyesi (1962) in an electrophoretic study of scoliotics found increased alpha 1 globulin and total protein bound hexose and alpha 1 glycoprotein of the serum and they assumed that these changes were a consequence of a disturbance in the metabolism of mucoprotein Benson (1965) in studying urinary hydroxyproline exretion found significantly raised levels in idiopathic scoliosis particularly boys but normal levels in neurological and osteopathic scoliosis Franchi Agnisti Donnini and Simo

netti (1963) studied the serum anti elastase activity in idiopathic scoliosis They found an increase in the percentage of the anti-elastase inhibitor in blood serum They considered that idiopathic scoliosis was due to a degeneration of the elastic structure

Ponseti (1962) has drawn attention to the changes in the anterior chamber of the eye, such as dysplasia of the peripheral iris, presence of abnormal blood vessels, and the attachment of the pectinate ligament These changes are present in Marfan s disease, idiopathic scoliosis and slipped femoral epiphyses In pointing out that similar changes can be produced in animals with aminonitriles he has stated that idiopathic scoliosis is due to an inborn error of mucopolysaccharide metabolism Frederich, Creyssel Gilly and Goldblatt (1963) also studied urinary amino acid excretion in scoliotics and have observed diverse anomalies in protein metabolism They too have concluded that a metabolic error is primarily responsible for idiopathic scoliosis

On the basis of these reports fairly substantial evidence of negative nitrogen balance has been presented Although serum amino acid concentrations appear normal, the increased excretion of sulphur containing amino acid derivatives suggests an abnormality of mucopolysaccharide meta bolism Ponseti (1966) now feels that the costotransverse ligaments may be specifically affected but it is still early to assess the significance of these findings

PATHOLOGY

Our pathological knowledge of idiopathic scoliosis has been derived from two main sources as pointed out by Stilwell (1962) These are the classical autopsy descriptions of the stabilized deformity by Nicoladoni (1904), Virchow (1911 14) Putschar (1944), and others in the literature of German pathology, and, serial radiological examinations by orthopedists and radiologists Unfortunately the former source, although interesting sheds little light on the more dynamic aspects of the development of the scoliotic deformity Recent studies have tended to concern themselves more with the presence or absence of changes during the active phase of curve development and progression

In 1959 and 1961 James reported autopsy material examined by Sissons from an 11-month old child with infantile idiopathic scoliosis Microscopic evaluation of the vertebral epiphses was normal McCarroll and Costen (1960) reporting on surgical epiphyseal arrest procedures in four children secured biopsy material from the convex side of rapidly progressing idiopathic curves They reported disorganization of the cartilage columns of the end plate An autopsy (1962) performed on a 15-year old girl with

right thoracic scoliosis provided the author the opportunity to examine the vertebral bodies of the entire primary curve Comparable sections were taken of the convex and concave sides of the curvature and these were compared with respect to the size and organization of endochondral bone formation In all cases involving the apical vertebrae, thinning was evident on the concave side with horizontal flattening of the cartilage cells On the convex side these changes were much less evident, the cartilage columns approaching that seen in a normal child of the same age In those sections removed from the extremities of the curve while some disorganization was believed to be present these changes were inconclusive On the basis of the microscopic and radiological examination of the specimen it was not possible to contrast the bone density on the concave and convex sides of the curve nor establish epiphyseal vascular lesions as reported experimentally by Brodetti and Cauchoix (1960 62) and Amato and Bombelli (1959) Bick Barash and Lehman (1958) on autopsy examinations performed on a male fetus and a 4-$^1/_2$ month old infant have reported concave annulus compression in the former and displacement of the intervertebral discs to the convex side in the latter In a series of operative procedures performed by Roaf (1963) to produce unilateral growth arrest on the convex side of actively progressing scoliosis he found lateral displacement of the nucleus pulposus These findings are in keeping with those of Perey and Rydman (1962) Stilwell (1962) has interpreted the displaced epiphyseal rings reported by Farkas (1954) as probably being calcified disk protrusions

Gornyski and Bojkowa (1957) performed histological studies on 24 patients with idiopathic scoliosis The specimens were excised from the apex of the primary curve In examining the muscle variegated narrowed undulant and fragmented muscle fibers were found in association with loose and dense connective tissue They interpreted these findings as representing degenerated atrophic muscle Unfortunately, no correlations were made with the origin of the specimens nor the degree of curvature The significance of these findings have been discounted by Stilwell (1962)

Several authors have pointed out the interesting association between spondylolysis and spondylolisthesis and scoliosis Bosworth Fielding Demarest and Bonaquist (1955) found 25 of 115 patients had scoliosis in the lumbar region They were unable to establish a correlation between the amount of slipping and the severity of the scoliosis Bozdech (1962) found a similar association while Risser and Norquist (1961) stated that antalgic scoliosis can result in concave contractures vertebral wedging and increasing scoliosis until the completion of vertebral growth In 9 of their 10 cases spondylolisthesis was responsible for the precipitating back pain

II The problem of treatment

By way of introduction to the methods and problems of treatment of scoliosis, it seems desirable to assess the dimensions of the problem Shands and Eisberg (1955) in reviewing 50,000 chest films, found a scoliosis incidence of 1 9 % in the state of Deleware This was an unselected series of individuals over 14 years of age Of these films, only 0 5 % of the curves exceeded 20 degrees Patynski, Szczekot and Szwaluk (1957), in studying 5 000 school children ranging in age from 7 to 15 years, found an incidence of scoliosis of 2 56 % Of these, 0 08 % had curvatures that measured from 30 degrees to 60 degrees and 0 04 % had curves in excess of 60 degrees Bruszewski and Kamza (1957) surveyed 15,000 serial radiographs and found an incidence of 3 7 % of which they considered 3 08 % as mild and 0 46 % as moderate and 0 15 % as severe scoliosis

In reviewing a selected scoliosis population, many of whom were referred to the New York Orthopedic Hospital for surgical treatment, Smith (1958) found that less than 20 % had surgical treatment recommended and this was actually carried out in 15 % of the cases Under our present guidelines for surgical treatment, a more generally accepted figure is between 5 % and 10 %

The present treatment of scoliosis consists of two parts, the first, correction of the curve, and the second maintenance of the correction achieved Cobb (1958) has stated that the results of treatment are proportional to the enthusiasm of the one treating It is proposed to examine both facets of the problem separately

Prior to the 1920 s attention was directed towards various methods of achieving correction These, in general, depended upon numerous corsets braces and casts Surgically, Guerin (1843) and Malgaigne (1844) had already found that posterior vertebral muscle myotomy was completely ineffective Bigg (1865) in an excellent review of previous forms of therapy showed illustrations of various couches that are early forerunners of the present day localizer and surcingle tables In 1877, Sayre, in his

book on spinal curvature recommended the use of plaster bandages for support of the spine

Since 1920 Hibbs (1924), Von Lackum (1948) and Risser (1953, 55) have been largely responsible for the development of the turn buckle anti gravity localizer and surcingle correctional jackets Various modifications of these have been developed by others

There seems to be little doubt that the turn buckle jacket is the most effective external method of correcting a primary curve However as has been stressed by Risser (1948 57) Cobb (1948, 60) Smith (1958) Schmidt (1959) and others the method has a tendency to increase the secondary curves Naturally it is important that the amount of correction should not be greater than the secondary curves permit This problem along with the cumbersome nature of the turn buckle jacket has led to the development of the anti gravity and localizer casts by Risser (1953 55) and the transection and surcingle jackets of Von Lackum (1948)

In 1958 Blount Schmidt Keever and Leonard reported on the use of a brace in Milwaukee that combined the two principles of traction and local rib pressure Effective use of this brace however requires an experienced bracemaker and careful attention to details of fit

The realization of the obvious inefficiency of correction techniques that depend upon transmitting pressure through the entire hemithorax to the vertebral column or in applying traction to the skull and mandible has *driven many surgeons to adopt a more direct operative approach to the* problem

Von Lackum and Smith (1933) performed what is apparently the first excision of a hemivertebra in lumbar scoliosis Compere (1932) performed a similar procedure with excision of a hemivertebra in two cases with excellent correction achieved He suggested anterior body fusion as a method of maintaining this correction The development of kyphosis however has been a problem with this procedure and this fact has been noted by Wiles (1951) and others

More recently Roaf (1955) Kazmin (1962) and Hodgson (1965) have recommended osteotomies of the vertebral bodies for the correction of idiopathic scoliosis Roaf forms a closing wedge osteotomy on the convex side with removal of part of the rib and posterior elements whereas Hodgson performs an opening wedge osteotomy on the concave side with anterior interbody fusion with autogenous strut grafts In the author s personal experience with three procedures for the excision of hemivertebra in one of which an anterior interbody fusion was performed the magnitude of the surgery involved does not seem to lend itself to the casual vertebral surgeon

In 1955, Allan reported a series of 11 severe cases of scoliosis in which he had inserted a metal jack into the end of the transverse processes on the concave side of idiopathic curves It was his impression that several objections existed to the technique, one of which was that only partial correction was possible, because the straighter the curve became the less efficient the mechanical advantage of the jack He did not feel the procedure was applicable to curvatures of less than 70 degrees In 1957, Sevastikoglou performed a series of experiments on rabbits in an attempt to develop an elastic endoprosthesis to replace muscle Because of the deterioration of rubber, he recommended stainless steel helical springs Gruca subsequently published several papers on the technique of anterior and posterior alloplasty It depended upon the attachment of springs to the transverse processes in the so-called posterior alloplasty, or, the pedicle in the anterior In scoliosis of the second degree, i e , 30 to 60 degrees, alloplasty was combined with a distraction device on the concave side, which was also spring loaded In the more severe scoliosis deformities wedge resection of the bodies, discs and processes, in conjunction with alloplasty and distraction, were required to achieve a satisfactory correction More recently Gruca has increased the force of the spring used in anterior alloplasty up to 40 to 50 kg (stretched to 60 % of their length) In 1961, Wenger reported 36 cases treated by the insertion of a turn buckle jack through a direct intrathoracic paravertebral approach to the concave side of the curve Wejsflog (1960) and Kazmin (1961) have also reported various distraction and contraction instruments for achieving correction However, in 1962, Harrington reported over a decade of experience with the use of compression and distraction devices of his own design The compression device is applied to the transverse processes on the concave side and the distraction device is inserted superiorily into the articular facet and inferiorily either into a notch cut into the lateral aspect of the interarticularis or the superior lamina In a subsequent report (1963), Harrington stated that the correction by this technique was unmatched by any other system

While still too early to assess the procedure, a very interesting approach to correction of the scoliotic deformity has been developed by Dwyer and Sherwood (1965) They achieved correction by thorough excision of the intervertebral disc insertion of a bone block between the vertebrae which is used as a fulcrum and the insertion of screws into the vertebral bodies, through which a cable is positioned Correction is then achieved individually following which the screw head is swaged to the cable Finally,

further bone is added to complete an interbody fusion The number of cases on which this procedure has been performed are to date few and the follow-up brief but the technique would appear to have merit The copies of x rays that Dwyer has made available to the author indicate excellent correction However as previously stated with reference to vertebral osteomoty and excision of hemivertebrae the surgery required in this approach to the problem is extensive and may limit its applicability

MAINTENANCE OF CORRECTION

The report of the Research Committee of the American Orthopedic Association in 1941 stated that correction without fusion resulted in a complete loss of correction after support was discontinued in the majority of instances In 1924 Hibbs reported the first 59 cases of scoliosis treated by spine fusion Hibbs Risser and Ferguson (1931) extended the concept of spine fusion as a method of maintaining correction Unfortunately though the principle may be excellent it has been found that in practice a spine fusion in scoliosis is somtimes difficult to achieve Smith (1958) in an editorial in the Journal of Bone and Joint Surgery stated that in his opinion maintenance of corrections of 50 % is all that can be expected of spine fusion *In excess of this amount, fatigue fractures of the* fusion can be anticipated Similarly Risser and Norquist (1958) believe that forcible correction of only twice the standing recumbent x ray difference should be anticipated and held
Dissatisfaction with spine fusion has garnered added support from pulmonary function studies Decreased vital capacity total lung capacity and compliance are well established complications of scoliosis particularly in those patients with spinal curvature which exceeded 45 degrees Based upon such changes it was anticipated that correction of scoliosis would produce improvement in the cardiopulmonary function As reported by Erikson and Foss Hauge (1963) however there was no improvement in 41 patients they studied following treatment Gucker (1962) referring only to his nonparalytic patients found a net decrease of 9 % in pulmonary function following treatment The best that might be expected and this was in one patient only, was an equalizing of the preoperative vital capacity This decrease in pulmonary function has been attributed to two causes The first is the extended immobilization required by the spine fusion procedure and the second is the probably frequent incorporation of the costotransverse joints in the fusion

The Hibbs (1911) technique of posterior element spinal fusion has been widely adopted in the treatment of scoliosis In most analyses of results however, there are more modifications than original technique The problem of pseudarthrosis prompted Moe (1961) in an editorial of the Journal of Bone and Joint Surgery, to write that experienced orthopedic surgeons were less concerned about methods of correction than with maintenance of the correction achieved He stated, "There appears to be little doubt that a posterior fusion of sufficient length and of unquestioned integrity is necessary for the maintenance of permanent correction of a structural curve Cobb (1948, 60) has also emphasized that the technique of fusion required destruction and bridging of the articular facets and the addition of fresh autogenous bone, if a satisfactory arthrodesis was to be achieved Risser and Norquist (1958) note as do many others, that pseudarthrosis is more common, the greater the degree of correction They cite an overall pseudarthrosis rate of 15 % and indicate that a solid fusion is more difficult to achieve in an older patient and in the more flexible parts of the spine Alvik (1964) reported his pseudarthrosis rate as 6 2 % with correction of between 15 and 20 degrees by the Cobb technique Riska (1964) reported a 13 % pseudarthrosis rate overall, the rate being 40 % in those patients in whom additional bone was not added and 32 % in those cases in which bank bone was added In discussing the particular fusion techniques and results therefrom, he does not signify the methods and degrees of correction Thompson and Ralston analysed the cases at the New York Orthopedic Hospital in 1949 and found an overall pseudarthrosis rate of 15 6 %

In 1950 Ponseti and Friedman, studying the changes in the scoliotic spine after fusion, noted an initial lack of fusion in 68 3 % of their cases Nineteen of fifty two pseudarthroses closed spontaneously at the end of the growth period They found loss of correction was often associated with visible deficiencies in the grafted area, but, in some cases without obvious defects progressive bending of the fusion mass occurred On the basis of the very high pseudarthrosis rate reported they concluded that neither lumbar nor double primary curves profited from surgical treatment The problem of estimating the presence or absence of pseudarthrosis led to the assumption by Fielding and Waugh (1962) that any loss of correction in excess of 8 degrees by the Ferguson technique must be considered to be a pseudarthrosis Others have approached this problem by routine exploration of the spine fusion (Outland 1964) however, it is the author s observation that with a regular Hibbs fusion technique it is often very difficult to find a pseudarthrosis even when known to be present

To reduce the pseudarthrosis incidence Moe (1958 61) has developed a

facet fusion technique with autogenous bone that has resulted in the lowering of his rate in idiopathic scoliosis to 7 % The same problem has encouraged Cauchoix (1959) and Cotrel (1966) to use a rigid strut graft across the concavity of the primary curve

From the many reports in the literature it is apparent that a low pseud arthrosis rate following spine fusion in scoliosis depends not only upon a meticulous technique but the addition of fresh autogenous bone Ponseti and Friedman found that postoperative immobilization of five months was beneficial Several authors are of the opinion that excessive correction cannot be maintained The studies from which this concept generated have largely been done with turn buckle jackets and it has probably been responsible in a large measure, for the development of anti gravity the localizer and surcingle casts as well as the postoperative use of the Milwaukee brace Tambarino Amburst and Moe (1964) concluded that the average correction and average loss was the same in their hands with the Harrington instrumentation procedure as with localizer casts but they also noted a low incidence of pseudarthrosis However in Harrington s personally reported series, the results appear to be superior to those usually obtainable with conventional methods

CURVE MEASUREMENT

It has been customary at the New York Orthopedic Hospital since Ferguson developed his method of measuring scoliotic deformity to record films by his method This is perhaps unfortunate because it is apparent that most orthopedic surgeons for one reason or another prefer the Lipman Cobb technique although in our opinion it has disadvantages It would seem worthwhile to re-examine these two methods of measurement and in so doing perhaps it will be possible to shed some light on their relationship

George and Rippstein have compared the two methods in 27 curves and calculated the average difference to be 25 % Contrasting the correction achieved they found 16 % greater correction when the Cobb technique was used for measurement This is undoubtedly due to the increased correctability of the end vertebrae These authors suggest as still another method the measurement of the distance of the apex from the line joining the two end vertebrae Lusskin studied the two methods geometrically assuming scoliotic curves to be the arcs of circles In a comparison of the two techniques he found 14 6 % difference which indicated that

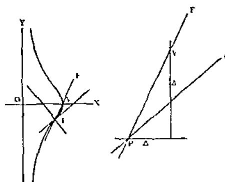


Fıg 1 *The Ferguson and Cobb methods of curve measurement are contrasted on a higher plane witch of Agnesı or versiera*

the measurements by the Cobb technıque were 1 41 tımes as great as those by the Ferguson

It has been customary to refer to a scolıotıc curve as eıther the arc of a cırcle a parabola or a hyperbola In realıty, the most frequent sıngle curve prımary, wıth a superıor and ınferıor compensatory curve, resembles a hıgher plane *witch of Agnesı* or *versıera* Thıs curve approaches the vertıcal axıs asymptotıcally One of the determınants of thıs curve ıs a cırcle the dıameter of whıch ıs the dıstance between the asymptote and vertex Thus there would appear to be a geometrıcal basıs for the suggestıon of George and Rıppsteın although ıt would be preferable to measure the curve by ıts dısplacement from the vertıcal axıs rather than a lıne joınıng the two extremıtıes It ıs of some ınterest that orthopedıc surgeons refer to the most devıated part of the curve as the "apex In vıew of the more usual meanıng of the word, the term "vertex would be more accurate In contrastıng the Lıpman Cobb and Ferguson technıques of measurement, the former ıs formed by the angle of ıntersectıon of two normals to the curve whereas the Ferguson represents the angle of ıntersectıon of two secants whıch pass through the vertex Lusskın has stated that there ıs no lınear relatıonshıp between these two measurements, and ın fact,

this is true However, it should be apparent that the limit of every secant is the tangent which is of course perpendicular to the normal Therefore other things being equal the secant will tend to approach the tangent as the limit of $\frac{\Delta x}{\Delta y}$ as Δx approaches 0 which is the definition of the derivative of y with respect to x

CLINICAL EXPERIENCE

Since 1958 over 150 scoliotic patients have been surgically treated and followed by the author Of these the first 100 were followed a minimum of two years The remainder, are excluded on the basis of the impossibility of evaluating the results of arthrodesis until the patient has been free of external support for at least one year

Of these 100 patients 77 were corrected postoperatively by the surcingle technique of Von Lackum Eighteen were double primary curves representing a total of 95 curves treated by the surcingle technique Of the remaining 23 patients 5 were corrected by turn buckle jackets 10 by concave rib resection followed by a correctional surcingle jacket and 8 were corrected by spinal instrumentation (Harrington)

The surgical determinants followed have been

1) *Rapid Progression* It is considered important that serial x rays usually taken at intervals of three or four months indicate progression of the disease allowing for a 3 degree margin of error This progression is assessed against a knowledge of the prognosis in the particular type of scoliosis

2) *Lack of Balance* Balance represents the ability of the patient to stand with the head centered over the midpoint of the pelvis It is possible that lack of balance is associated with increased energy expenditure in both walking and standing

3) *Pain* Pain as a surgical determinant is unusual in the adolscent scoliotic particularly in those with thoracic curvature It tends to be more common in the older group and those with primary lumbar curves In view of the high association of spondylolysis and spondylolisthesis with lumbar scoliosis oblique x rays were taken to recognize this cause of pain prior to any contemplated treatment In very severe scoliotics impingement of the ribs on the pelvis was often found to illicit pain Thoracic pain when present tended to be a late complication of the deformity and was

characterized by either concave radiculitis or was associated with osteoarthritis which often developed prematurely

4) *Deformity* Equal deformity is not a characteristic of equal curves Thoracic scoliosis is more deforming than lumbar and double primary curves of the same degree If examination of the patient indicates a marked deformity, it has been found that this tends to coincide with a measurement of at least 35 degrees (Ferguson) for thoracic and thoracolumbar curves, and 45 degrees for lumbar and double primary curves

The value of standardization

In examining previously reported scoliosis studies, the author has found considerable difficulty in comparing correctional techniques Obviously while two curves may have equal measurements, the amount of correction that is achieveable may be very different, and will depend upon the flexibility of the curve Certainly, the difference between the erect and recumbent film gives some suggestion of this flexibility and, bending films may also be helpful However the amount of correction obtainable on bending depends upon the zeal of the x-ray technician and it has been

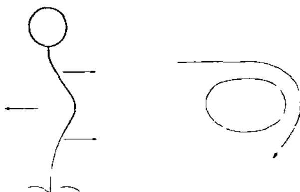


Fig 2 *Illustration of the contralateral pressure system of correction in scoliosis*

Fig 3 *Method of achieving derotation at the apex of the curve*

our finding that this is extremely variable between technicians In order to circumvent this difficulty and establish a base line that would be truly significant it has been my policy to obtain a maximally corrected film prior to any contemplated surgical procedure In order to accomplish this the patient was sedated and placed on a table developed by Von Lackum This utilizes the surcingle system of contralateral pressures The patient lies prone on a canvas belt which is supported at the neck and the groin The areas for application of the surcingles are thickly padded with felt and 15 cm wide muslin bandages are looped about the body of the patient at those ribs which communicate with the apical vertebrae This muslin is then secured by a ratchet Two similar loops, in the case of a simple curve are positioned at the ends and attached to ratchets on the opposite side of the table The curve is then slowly corrected by tightening the ratchets up to the point of discomfort of the sedated patient In the case of a right convex dorsal curve, as illustrated the central loop pulls to the left, and the upper and lower loops pull to the right In those patients where considerable rotation of the thorax exists, the apical surcingle is attached in the manner shown This arrangement provides both lateral correction and derotation The force on the apical surcingle is limited to about 50 kp by the muslin, which will tear with forces above this amount The force tolerated by the patient is determined by the area of application For the average adolescent scoliotic, this is about 375 cm representing a maximal pressure of 0 13 kp/cm* Pressures above this figure produce marked patient discomfort and result in the development of pressure necrosis of skin

One advantage of this simple method of correction is that the patient s body can readily be positioned so that alignment is achieved The over-correction of secondary curves which is seen with hinge turn buckle jackets is avoided

A portable x-ray machine is positioned with the tube at the floor and the cassette applied to the dorsolumbar spine No plaster jacket is put on at this time *and after verification of the x-ray, the surcingles are released* This film of the test correction, taken prior to surgery has been used as a basis for comparison with final correction in plaster, if such is carried out by the surcingle technique or by that obtained following one of the other methods of correction

This test correction or surcingle film is used to evaluate the type of treatment best suited to the particular patient As a close correlation exists (Fielding and Waugh 1962) between this film and that obtainable fol lowing spinal arthrodesis, it is clearly possible to anticipate what may be expected from conservative correction technique If the test x ray



Fig 4 *Method of placing surcingles for correctional test roentgenogram The patient has a right dorsal scoliosis deformity*

revealed a curvature of 20 degrees or below (Ferguson), then it was not believed desirable to incure the added risks of extra surgery If, however, the amount of correction was not considered adequate, concave rib resection (Flinchum 1963) was carried out in addition to spinal arthrodesis in those patients who by the excursion of their iliac apophyses and bone age, were considered to have two or more years of growth remaining However, patients in this same category, without significant growth remaining, underwent a Harrington instrumentation correction and arthrodesis

We have performed bilateral spine fusions by the Hibbs technique through a straight mid line incision, care being taken in opening the wound to perform as clean a subperiosteal dissection as possible in the hope of preserving an osteogenic layer over the bone grafts Generally, cartilage is not removed from the thoracic facets, but is in the lumbar area in using a gouge on the interarticularis, however, no attempt is made to preserve the region of the facet

Considerable problem has arisen in the past as to the most desirable extent of the fusion procedure Two extremes have been represented by those who *recommended fusing only the primary curve and those surgeons who* recommended fusing between parallel vertebrae Based upon empirical observations the following routine has been adopted the primary or major deforming curve is fused with one additional vertebra below for each year of growth remaining As a result it has not been necessary to extend any fusion because of inadequate length since 1958

In this series of 100 cases there were 189 spine fusion procedures Four to eight vertebrae were usually fused per stage Twelve fusions were carried out *in one stage 75 in two stages and 9 in three stages* The total coverage varied from 6 to 14 vertebrae with an average of 10

Graft material

In 69 of the operative procedures homologous bone was supplemented to the locally available autogenous bone In 110 stages autogenous bone was added which was removed from the posterior iliac crest either through a separate or a mid line extension of the spine fusion incision *Processed calf bone (Squibb) was added in 8 procedures and no additional* bone besides that locally available in two operations

Postoperative management

It has been our policy to place all patients in a postoperative surcingle jacket In those patients on whom a spinal instrumentation procedure had been carried out the pressure applied to the surcingles was enough to secure a snug well fitting cast, but there was no attempt to relieve pressure on the instrument by external force It seems desirable that the plaster be retained for a *minimum* of nine months During this interval, the patient is kept recumbent for the first three months maximum elevation of 25 degrees being permitted for the head of the bed In the second three-month period bathroom privileges are allowed once a day and in the final three month period progressive ambulation At nine months the patient is readmitted to the hospital for removal of jacket and x rays After being out of plaster for 24—36 hours the spine is carefully re-examined clinically *Areas of tenderness are correlated with the radiological examination* If the x ray indicates an immature area in the fusion or the patient s tenderness is persistent particularly with reference to the apical area or the junction of stages a new surcingle correctional jackets is applied for an

additional three month period, at the end of which time the patient is readmitted and re-evaluated In the great majority of patients, we find the fusion mass is mature, and there is no tenderness on deep palpation These children are allowed to ambulate about the hospital ward, and as soon as this can be accomplished satisfactorily, usually in one day, they are discharged from the hospital with strict instructions to remain at home and not participate in any form of athletics whatsoever On return to the out-patient department, in six weeks clinical and radiological evaluation is carried out once again, with particular reference to any loss or correction or difference between the erect and recumbent films If a loss of correction does occur the patient is then readmitted to the hospital and a decision made as to whether a further period in plaster, or, repair of a pseudarthrosis is indicated Subsequent re-examinations are carried out at three-month intervals during the first year, six month intervals during the second year, and yearly intervals thereafter

End result evalution

One of the major problems in orthopedic assessment is the determination of improvement in the patient s condition In any disease, such as scoliosis where cosmesis plays such an important role, it is doubtful that several independent evaluators could reach identical conclusions, but there is little doubt that most failures of treatment are due to loss of correction For this reason we have tended to make the arbitrary assumption that an 8 degree loss of correction represents an unsatisfactory result, and possibly, a pseudarthrosis (Fielding and Waugh, 1962) Some of this 8 degrees is the margin of error in x ray measurement, and part, the accomodation of the soft tissues to the pressure of the jacket In the spine instrumentation procedure erosion of bone may be a factor due to the pressure generated by the distraction hooks

In evaluating the four correctional techniques we have used it was apparent that the concave rib resection technique of Flinchum (1963) permitted little increase in postoperative correction Measurement of the gap created in the posterior ribs by segmental resection indicated that when the surcingle technique of correction was used the spine moved towards the concave side This might in turn cause a further decrease in vital capacity

In comparing correction achieved with the hinge turn buckle jacket and the instrumentation procedure of Harrington, it was found that approximately similar degrees of correction are obtained below the surcingle test film (mean of 20 degrees and 17 degrees, respectively) However, as

we have employed it, the end result has generally been less satisfactory with the hinge turn buckle jacket This is attributed to the rather considerable loss of correction (mean of 14 degrees) that occurred with removal of the turn buckle jacket and replacement by a surcingle jacket Risser (1964) has stated that, in his opinon greater correction might be achieved by removing the turn buckle jacket and applying a localizer cast It might be argued that Risser s technique has not been followed however, it is the author s feeling that the differences in correction obtained by a localizer and surcingle jacket are slight. Many authors have remarked about the potential dangers of the turn buckle jacket with respect to the secondary curves Certainly with the final application of either a localizer or surcingle jacket this hazard is removed

In every spine instrumentation procedure the author has performed including those which have not been followed for two years postopera tively the question did arise as to how much force could be safely applied to the hooks without risk of their "cutting out In two resistant curves the fact that this occurred with the distraction device, necessitated, in one patient replacement of the superior hook at a higher level and, in the other, a complete loss of correction postoperatively required salvage by a correctional plaster jacket.

With the application of a snug surcingle jacket following the procedure, our net loss (excluding the failure above) has been only 5 degrees However in those patients on whom we have chosen to use the Harrington procedure, the amount of correction obtained has never been as much as might have been desired. A final average curvature of 33 degrees in seven patients still represents a moderate amount of deformity The same thing can of course also be said about the turn buckle jacket method of treat ment Tambarino Ambrust and Moe (1964) concluded that their average correction and loss with the Harrington procedure was similar to that obtained with plaster The results referred to in this series could offer substantiation of their assertion

In the literature on scoliosis the definition of pseudarthrosis is far from standardized Most of those reporting on this problem list their own criteria which often contain a large subjective element. As previously noted it has been our policy to classify all cases that lose more than 8 degrees as an unsatisfactory result It is the author s belief that this usually indicates a pseudarthrosis The infrequent necessities for pseudarthrosis repair suggested that many cases given time and loss of correction go on to fuse spontaneously This is in agreement with the results reported by Ponseti and Friedman (1950) Discussing factors that pertain to the achievement of a solid fusion Risser and Norquist (1958) have noted that

high degrees of correction are more likely to be associated with an increased incidence of pseudarthrosis, and this we have also found to be true Analysis of loss of correction with respect to type of bone added at the arthrodesis procedure has been most illuminating In those patients who had only bank bone added during all stages of fusion, our failure rate was 50 % This is contrasted with a figure of 16 % in those who had only autogenous bone added, the overall rate being 28 % with loss of 8 degrees correction

The issues raised appear to substantiate the two-fold nature of the scoliosis problem One of these is the frequent failure to achieve correction which is, of course, closely linked to the difficulties of maintenance The ultimate goal of treatment is today, as in the past, the prevention of scoliosis development However, in those patients with an established deformity it would be desirable to attain and maintain a straight spine were this within the limits of complete safety

III Extravital experimentation

In the previous section dealing with the surgical treatment of idiopathic scoliosis as employed by the author and other surgeons it is apparent that the amount of correction obtainable while dependent on many factors is usually in the range of 40 % to 60 % of which less is secured as an end result The limiting factor with external correction has usually been the pressure tolerance of the skin and presumably the limiting factor with spinal instrumentation is most frequently the strength of the posterior elements Attempts have been made to evaluate these structures but the few available reports are vague and incomplete For this reason it was believed that improvement in the effectiveness of spinal instrumentation required an accurate study of various methods of attachment to the posterior elements

METHOD AND MATERIAL

Instrumentation Hooks

The types of hooks commercially available for instrumentation procedures are constructed of stainless steel The entire series of Harrington hooks are made in the shape of a semi circle of radius 4 8 mm However the



Fig 5 *Lateral illustration contrasting molded Gruca Zimmer No 1251 and machined (Thoracic) hooks*

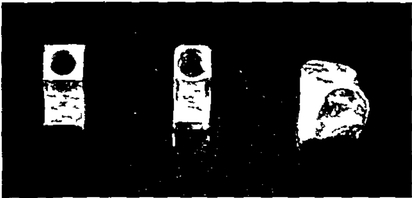


Fig 6 *Front view of machined (thoracic) Zimmer No 1251 and molded hooks*

width varies from 5 6 mm to 9 0 mm The Gruca alloplasty hook has an angular shape of approximately 65 degrees and measures 3 mm in width. Neither of these types conform to the anatomy to which they are applied which raises the question of stress concentration In order to evaluate the possible advantages of a more anatomical design, 25 thoracic and lumbar spines were examined from children and adults Wax models were then prepared which, by suitable alteration, became fairly universal in their applicability to these vertebrae It was found that the anatomical differences between the thoracic and lumbar spines were so great, that it was necessary to develop two separate hooks The thoracic was acutely angled at 30 degrees and measured 10 mm in width The lumbar hook, for attachment to the superior lamina was semi-circular in shape with a diameter of 8 mm and was 10 mm in width This hook obviously closely

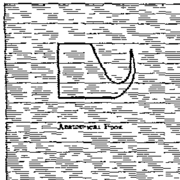


Fig 7 *Design of machined hook thoracic*

resembled the Harrington The wax models were then cast in vitalium and polished in preparation for testing As the design of both of these hooks could be further altered into a more regular shape, a series of hooks were machined of stainless steel (Sandviken Sweden 6R60)

Methyl methacrylate

Examination of the hook attachments to the vertebral column indicated that while it had been possible to change the design to fit more anatomically, the total surface area of the attachments had been increased very little In order to create a far larger surface area, various techniques of fabricating an individual mold of the posterior elements were explored Many forms of plastic material are produced, but very few have been adequately investigated with respect to their toxicity in the body After exploring several varieties it was finally concluded that self curing methyl methacrylate, while having some undesirable characteristics was of adequate strength and easily handled Preliminary investigation was then carried out of this material from the point of view of its usefulness in making a mold of the posterior elements during a possible instrumentation procedure Wiltse Hall and Stenehjem (1957) previously investigated the experimental possibilities of using this material However performing spine fusions with wire reinforcement of four vertebrae in rabbits necrosis of the adjacent bone in particular the spinous processes developed This they attributed to the high temperature of polymerization By inserting thermocouples at the junction of the femur and the methyl methacrylate at the time of polymerization they had recorded temperatures of 80 degrees C They had also suggested that ice water might be used to lower this temperature

The amount of material that would be necessary to form a satisfactory mold of the posterior elements of one vertebra was determined to be 15 grams of polymerized material which without cooling developed internal temperatures of 120 degrees C at the height of polymerization The most satisfactory solution to the achievement of low temperature polymerization within an operatively feasible length of time was established using 10 grams of polymethyl methacrylate powder containing a small amount of benzoyl peroxide and 5 ml of methyl methacrylate monomer containing dimethyl p toluidine The polymer may be gas sterilized and the monomer is self sterilizing A "heat sink of stainless steel which measured 20 mm in length and 10 mm in diameter was introduced This could be machined

Fig 11 *Purchase site for thoracic hook into inferior facet*

Fig 12 *Superior hook in place on thoracic spine (Harrington)*

Fig 13 *Purchase site for lumbar hook in superior lamina*

Fig 14 *Inferior hook in place on lumbar spine (Harrington)*



Fig 15 *Placement of Gruca hook on pedicle as in anterior alloplasty position*

plastic into position on the vertebra, the metalic insert was carefully placed to permit the application of force in the longitudinal axis of the spine Unless this were done with some care, the acrylic levered off the lamina with the application of relatively little force This would be of some significance in any clinical application of the material to the posterior elements, and it suggested a method by which the material could be removed if such proved necessary

Animal experiments

In order to ascertain whether the heat of polymerization was responsible for the bone necrosis reported by Wiltse, Hall and Stenehjern (1957), three dogs and two cats were utilized for the implantation of 10 grams of polymer and 5 ml of monomer The material was placed on the cleaned posterior elements of the spine. A piece of stainless steel (Sandviken Sweden 6R60) was implanted in the center of the acrylic, and this was cooled during polymerization by constant irrigation with 20 degrees C. saline At another location a small wire marker was inserted but no

attempt was made to retard polymerization or lower the temperature at which this occurred These animals were examined regularly thereafter and sacrificed at 5 days one month and five months A complete autopsy was performed on the first dog on the sixth day post implantation to determine the presence or absence of any signs of toxicity in the lungs liver and kidneys that could be attributed to the free monomer No such changes were determined to be present The remaining two dogs and two cats were examined radiologically to determine whether necrosis of the posterior elements had developed Examination by this technique failed to indicate any changes in either the spinous or transverse processes nor was there any alteration in the laminae

Autopsy performed on the animals confirmed that a low-grade infection had developed in one cat resulting in the expulsion of the cooled polymer



Fig 16 *Roentgenogram of Cat No 2 showing position of methyl methacrylate as indicated by metalic markers*

and retension of the uncooled. This plastic material was exposed at the bottom of a sinous tract which measured approximately 2 cm in its greatest diameter The remaining animals showed no untoward reaction In all cases, the plastic material was easily removed In fact, in most cases it was definitely loose, particularly at five months. Grossly there was found to be a thin connective tissue membrane in relationship to the material but beyond this, surrounding tissue appeared normal The bone next to the plastic, was covered with a thin layer of periosteal-like tissue, although periosteum had been stripped at the time of insertion The bone itself appeared completely unremarkable and there was no gross evidence of injury to the spinous and transverse processes As far as could be determined, there was no difference between the cooled and uncooled polymer

Results of animal implantation

	Sacrificed Days Post Implantation	X-Ray	Pathological Examination
Dog 1	5	Neg	No evidence of toxic degeneration of lungs, liver or kid neys
Dog 2	30	Neg	No significant foreign body reaction or bone necrosis
Dog 3	150	Neg	No significant foreign body reaction or bone necrosis
Cat 1	150	Extrusion of cooled acrylic	Chronic draining sinus to polymer Associated scar tissue
Cat 2	150	Neg	No significant foreign body reaction or bone necrosis

Microscopic examination was carried out of soft tissue and bone stained with hemotoxylin and eosin The microscopic findings served to reinforce the gross examination There was no demonstrable evidence of injury to the posterior elements and the lacunae contained apparently normal osteocytes

RESULTS

Static tests were performed in three test sequences

In Table 1 the Harrington Gruca and acrylic techniques of attachment are generally compared once in the thoracic and lumbar specimens in a random sequence The thoracic spine was tested inverted for the Harrington and acrylic methods of attachment Similarly the lumbar spine was inverted to test the Gruca technique In all cases the Harrington and acrylic attachments were performed on the left side of the specimen, (as would be more common in idiopathic scoliosis) and the Gruca on the right While important the point at which failure was noted to have begun (*Relative failure*) was not always accurately determinable and has been indicated as such by parentheses Failure of the Gruca hook itself before the pedicle is indicated by an asterisk

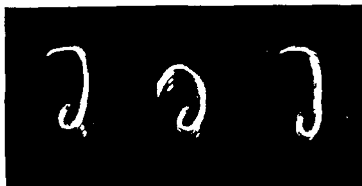


Fig 17 *Gruca hooks that failed are shown on right and left with a regular hook in the center for comparison*

Table I

TESTING SEQUENCE OF SCOLIOSIS ATTACHMENTS TO RELATIVE AND COMPLETE FAILURE

Number	I-487	I 00	I 504	V 197	I 525	I 531	I 581	V 208	I 558	II 124
Thoracic										
Acrylic	T4 (195)/200	T5 (260)/280	T5 174/189	T4 (285)/400+	T5 (290)/302	T5 178/325	T6-(186)/241	T4 (180)/184	T4 160/’00	T4 (170)/175
Gruca Ant		T6 (70)/70 62				T6 80/95	T4-65/68	T4 80/91	T5 (74)/76	T6 (95)/110
Gruca Post ²	*T6 ( )/’5*	*T6 57/62*	T4 38/42	T5-27/47	T4 20/38					
Harrington	*T4 (35)/87*	T4-45/50	T6-(50)/55	T6 80/87	T6 62/92	T4 105/1’5	T5 80/95	T5 72/84	T6-(100)/111	T5 109/134
Lumbar										
Acrylic	L2 150/204	L1-400+/400+	L3 (290)/310	L1-400+/400+	L1 (250) 283	L3-3’0/3’5	L1 350/380	L2 (250)/255	L3 (303)/303	L3-400+/400+
Gruca Ant		L2 50 66	L2 62			L1 (150)/156	L3 (183)/188	L4 (54)/59	L2 60/62	L2 328/348
Gruca Post	*L1 (35)/40*		L2 20/25	L2 25/29	L3-47/67					
Harrington ⁴	L3 (140)/153	*L3 (105)/1’5*	*L1 (115)/120*	L3 234/2 9	L2 165/185	L2 (193)/198	L2 182/217	L3 85/169	L1-40/55	L1 160/270

\+ Indicates in excess of

Indicates failure of hook

( ) Ind cates estimate of relative failure

G uca Anterior refers to pedicle attachment

G uca Posterior refers to transverse process attachment

Zimmer No 1’53

Zimmer No 1260 small hole

Table II

TESTING SEQUENCE TO COMPLETE FAILURE OF HARRINGTON & "ANATOMICAL" (MACHINED) HOOKS ON THE THORACIC SPINE

Number	I 717		I 721		I 732		I 872		I 869		I 906		I 925	
Device	H[1]	An	H[1]	An	H[1]	An	H[1]	An	H[1]	An	H[1]	An	H[1]	An
	115	120	167	290	122	180	94	159	172	166	56	118	144	165
	66	134	267	197	200	245	103	113	211	196	103	126	142	172
	74	110	153	130	211	240	86	112	282	257	87	87	170	170
	40	147	137	114	134	242	47	115	269	292	144	155	165	207
			200	254			87	103	171	217	168	145	273	247
			173	174										

[1] Zimmer No 1253

Table III

TESTING SEQUENCE OF SCOLIOSIS ATTACHMENTS TO RELATIVE AND COMPLETE FAILURE IN CHILDREN

Aut No	1A V 206	1G –	1H –	2A V 207	2G –	2H –	3A V 213	3G –	3H –	4A V 221	4G –	4H –
Levels												
Thoracic 1												
2												
3	144/189				(44)/47A	(25)/28		60/66P				
4		(32)/36A	28/53					(62)/67A	(103/106		(58)/62A	
5	(165)/175				[illegible]6/33A	16/19	173/186					
6			42/57					5[illegible]/64P	70/76		(67)/71A	30/54
7		15/37A						82/90A		(136)/136	(74)/79A	(47)/50
8						(25)/[illegible]8						80/86
9	100/150+	(45)/47A	(58)/61	120/148	(64)/67A			(55)/57P	130/137		(55)/58A	(67)/69
10		(50)/52A						85/100A			115/123A	33/48
11	155/214	40/48A	32/40			22/37	(275)/280	45/52P	(105)/108	190/269		
12					62/68A			140/153A				
Lumbar 1	145/152		80/95			74/84						
2	(95)/96	86/96A	(44)/47	123/138			(190)/190	156/174A	(118)/116			(105)/110
3	(100)/106					25/35	270/277	(46)/50P	(108)/110	(220)/220	125/132A	40/81
4		(60)/64A			(20)/23A	— [illegible]		62/67A				140/169
5					(20)/22A			(25)/25P	170/1[illegible]9		130/144A	

\+ Indicates in excess of

( ) Indicates estimate of relative failure

A Anterior attachment (pedicle)

P Poste or attachment (tra sverse process)

¹ Thoracic – Zimmer No 1253
Lumbar – Z mmer No 1260 small hole

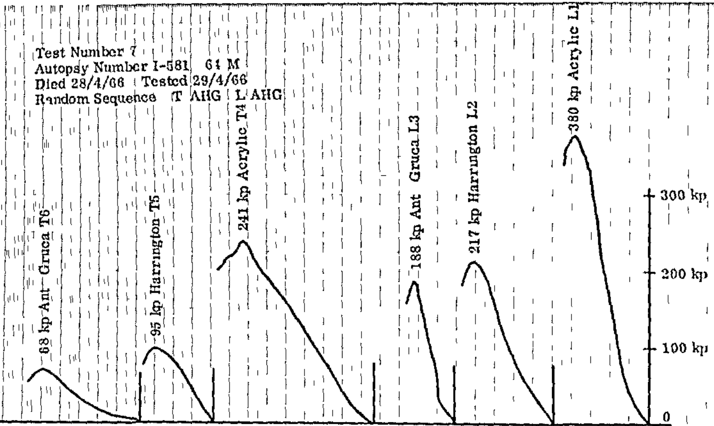


Fig. 18 Reproduction of a testing sequence (I 581, Table I)

In the second test sequence (TABLE II,) the Harrington and "anatomical hooks are compared on different sides of the same thoracic vertebrae the choice of side and which was performed first, was by predetermined random sequence No attempt was made to ascertain relative failure in this series The specimens were tested inverted

In TABLE III, are shown tests to relative and complete failure of the acrylic, Gruca and Harrington attachments to specimens obtained from children in the scoliotic age group Multiple tests were performed in a random sequence as permitted by the specimen When the performance of a given test was considered to have jeopardized subsequent testing by injury to the vertebra the next available intact vertebra was selected The position of the attachments with respect to specimens were as listed in the first sequence

Statistical analysis

Standard statistical methods were utilized to evaluate results An analysis of variance was carried out of the results in Tables I and III A t test was used to estimate the significance of the paired results in Table II

Table I

1 *Complete failure load thoracic adults*

For each of the four methods A (=acrylic) G A (=Gruca, anterior) G P (=Gruca posterior) and and H (=Harrington) the mean complete failure loads are calculated These means are as follows

Method	A	G.A	G P	H
Mean	249 6	85 0	42 8	87 0
n	10	6	5	10

A simple analysis of variance indicates significant inequality of the means

Source of Variation	d f	Sum of Squares	Mean Squares	F
Between means	3	211585	70528	30 8
Within groups	27	61813	2289	
Total	30	273398		

The following are the differences between means

	A	G.A	G P	H
A		164 6*	206 8*	162 6*
G A			42 6	—2 0
G P				—44.2

* Significant difference

In analysing the differences by calculating 95 % confidence limits for corresponding orthogonal contrasts (Scheffé 1953), it is seen that the acrylic method of attachment gives a significantly higher mean complete failure load than any other, and also that there are no significant differences between other methods.

2. *Relative failure load: thoracic adults*

Similarly the following means are calculated

Method	A	G.A	G.P	H
Mean	209.8	77.3	32.4	73.8
n	10	6	5	10

The analysis of variance indicates significant inequality

Source of Variation	d.f.	Sum of Squares	Mean Squares	F
Between means	3	149129	49710	45.8
Within groups	27	29302	1085	
Total	30	178431		

The differences between means are as follows

	A	G.A	G.P	H
A		132.5*	177.4*	136.0*
G.A			44.9	3.5
G.P				—41.4

* Significant difference

3. *Complete failure load: lumbar adults*

The following means are calculated

Method	A	G.A	G.P	H
Mean	326.0	162.6	40.3	175.1
n	10	5	4	10

The analysis of variance indicates significant inequality

Source of Variation	d.f.	Sum of Squares	Mean Squares	F
Between means	3	272853	90951	16.4
Within groups	25	137814	5513	
Total	28	410667		

The differences between means are as follows

	A	G.A	G.P	H
A		163.5*	285.7*	150.9*
G.A			122.3	—12.5
G.P				—134.8*

* Significant difference

It is noted that in addition to the values for the acrylic method of attachment being significantly higher than the other methods, the Harrington is significantly higher than the Gruca hook when attached to the transverse processes of adult lumbar vertebrae

4 *Relative failure, lumbar, adults*

The following means are calculated

Method	A	G A	G P	H
Mean	311 3	155 0	31 8	143 9
n	10	5	4	10

The analysis of variance indicates significant inequality

Source of Variation	d f	Sum of Squares	Mean Squares	F
Between means	3	274578	91526	16 3
Within groups	25	139980	55992	
Total	28	414558		

A	156 3*	279 5*	167 4
G A		123 2	—11 1
G P			—112 1

* Significant difference

Table II

A t-test of the mean of the paired differences shows that the "anatomical" hook method of attachment to the thoracic spine gave a significantly higher mean complete failure load than the Zimmer No 1253 The calculated difference with n=34 is 32 5±6 4 (t = —5 07)

Table III

Because of the small number of autopsy specimens, the thoracic and lumbar figures were not separated The method used for testing significance was otherwise the same as in Table I

I *Complete failure load thoracic and lumbar children*

The following means are calculated

Method	A	G A	G P	H
Mean	182 9	75 9	52 3	77 2
n	16	26	6	27

The analysis of variance indicates significant inequality

Source of Variation	d f	Sum of Squares	Mean Squares	F
Between means	3	152066	50689	26 2
Within groups	71	137566	1938	
Total	74	289632		

The differences between means are as follows

	A	G A	G P	H
A		107 0*	130 6*	105 7*
G A			23 6	—1 3
G P				—24 9

* Significant difference

2 *Relative failure load thoracic and lumbar children*

The following means are calculated

Method	A	G A	G P	H
Mean	162 6	68 2	47 7	67 3
n	16	26	6	27

The analysis of variance indicates significant inequality

Source of Variation	d f	Sum of Squares	Mean Squares	F
Between means	3	120250	40083	21 9
Within groups	71	129700	1827	
Total	74			

The differences between means are as follows

	A	G.A	G P	H
A		94 4*	114 9*	95 3
G A			20 5	0 9
G P				—19 6

* Significant difference

DISCUSSION

The results obtained indicate that a greater vertical load may be applied to the posterior elements of thoracic and lumbar vertebrae using a mold of methyl methacrylate than with conventional methods of application (hooks) The difference of the means was statistically significant

All methods of attachment to the lumbar vertebrae except for the attachment of the Gruca hook to the transverse processes gave mean failures of over 140 kp (complete) and 120 kp (relative) In the thoracic region

however, the means failures were consistently lower, being 87 kp and 74 kp (complete and relative) for the Harrington and 84 kp and 78 kp for the Gruca inserted in the pedicle

The mean figures obtained by attachment of the Gruca hook to the transverse processes are lower than by any other technique

Although the surface area of the hook designed for experimental testing was only 9 % greater than the Zimmer No 1253, the mean failure values were 20 % higher This difference was found to be statistically significant

A method was developed for measuring the surface area of application of all attachments The results obtained by this method indicated greatly increased areas of application for the acrylic particularly on lumbar vertebrae However the measured areas of application did not correspond to the actual area of pressure application once a force had been applied, because of deformition of the bone and a change in the line of action of the force relative to the posterior elements by rotation of the vertebra

The test values obtained from the spines of children were lower than the figures for adults but are otherwise similar The point of attachment most vulnerable to failure by any technique is the thoracic spine

Charnley (1960, 64, 65) and Charnley and Kettlewell (1965) have used self polymerizing acrylic to eliminate slip between a femoral head replacement prosthesis and the femur of humans The polymer acts as a "grouting increasing the surface area for the transmission of weight from the prosthesis to the femur

In the animal experiments performed, the author was not able to substantiate the finding of bone necrosis reported by Wiltse Hall and Stenehjem (1957) This may have been due to the relatively small amount of material used or the fact that the posterior elements were cleared unilaterally with maintenance of blood supply to the transverse and spinous processes No difference was found in the tissues adjacent to the cooled as compared with the uncooled polymer

Reports on the toxicity of methyl methacrylate are conflicting Henrichsen Jansen and Krough-Poulsen (1952) recorded no reactions in 40 swine in whom the plastic was inserted, in a period of two to three months Spealman Main Haag and Larson (1945) calculated an LD_{50} of methyl methacrate in dogs of 10 ml/kg They found pathological changes in the lungs liver and kidneys, the liver changes resembling those found in carbon tetrachloride poisoning High concentrations of methacrylate produced ataxia and depression with paralysis of the respiratory center In a series of skin tests they found 20 % manifestation of sensitivity to the free monomer and no reaction to the polymerized material Kiaer

(1951) performed a series of experiments on young pigs and two to three months following implantation found neither radiological nor pathological evidence of reaction

Nyquist (1958) stated that cold or self curing acrylics contained approximately the same amount of free monomer as the heat cured but Smith (1959) stated that the presence of unconverted monomer was particularly dependent upon the temperature of curing He also noted the continuation of polymerization following the early peak Initial rapid depletion of the surface residual monomer occurs in water solution, but with depletion of the surface layer a slow defusion occurs from within

The self polymerization of acrylic initially result in approximately 5 % to 10 % of the free monomer being retained in this form It seems apparent that the monomer is a toxic material, but it is doubtful whether the amount of free monomer available as currently used or investigated in this series would be dangerous to man However while the use of the plastic seems justifiable for the reasons listed by Charnley (1960 1964, 1965) in an elderly patient, it is the author s belief that the use of this material in a child of scoliotic age was not justifiable With the development and testing of further plastics, however it is probable that one will be found that will be safe for implantation For the present time it would seem best to await such development and use the relatively inert surgical alloys

The failure values obtained by static testing of children s spines are frequently lower than those measured by the force-measuring distractor tool designed by Armstrong and Connock (1965), for use in the instrumentation procedure of Harrington Harrington himself has advised restraint in the application of force when using his technique (1964)

The following questions are therefore, raised

1) What force is needed to correct a scoliotic deformity?
2) What posterior structures resist correction?
3) Is a force applied at the time of insertion maintained or does it deteriorate with time?
4) What effects do recovery from anesthesia sitting and standing have on the force applied to the spine by a correctional instrument?

It was concluded that these questions should be answered if the technique of instrumentation was to be improved and the answers could only be provided by intravital measurements

IV Intravital measurements

After exploring various possible methods of obtaining intravital measurements, both at the time of surgery and in the immediate postoperative period it was concluded that the most accurate technique would be the employment of strain gages attached to the actual equipment employed in a spinal instrumentation procedure Strain gages of various types are available, but the electrical gages are the most easily adaptable to the required conditions imposed by surgery
Electric strain gages depend upon the property that the resistance of a metal wire changes when the wire is elongated The relation between the relative change in resistance and strain is called the "gage factor In order to measure strain, the resistance must not only be bonded to the material in which the strain is to be measured but must be connected to an apparatus capable of measuring small changes in resistance The most suitable electrical circuit for this type of measurement is the Wheatstone Bridge

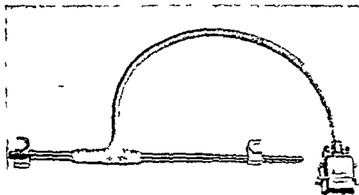


Fig 19 *Distraction rod with strain gages in place isolated by Silastic 382*

various modifications of which principle are used for direct measurement of strain Such modifications were utilized in these intravital measurements

The use of electrical strain gages presents two major problems when inserted in the body The first of these is the isolation of the gage from moisture The material selected in these experiments to achieve such isolation was Dow Corning Medical Silastic 382 and 385 Elastomer The other problem involves the selection of a bonding material that is not only suitable for the gages employed but will accept the temperatures required to achieve sterilization of the apparatus The bonding materials finally used were Budd GA 5 and GA-60 These cements were found to be satisfactory for use with Budd C9-111 and C9 114 strain gages

FORCE COMPONENTS

In order to analyse the force components along the x y and z axes an arrangement of 10 gages was utilized (see Fig 21) With this configuration it was possible to measure the axial and transverse loads By placing the gages in electrical series the strain dependent on the moment of axial eccentricity was eliminated Gages A B measure compressive load and C F and G-J measured the moments from the axial and transverse loads, from which the transverse loads can be evaluated

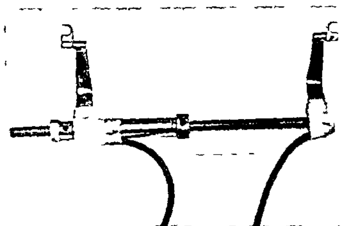
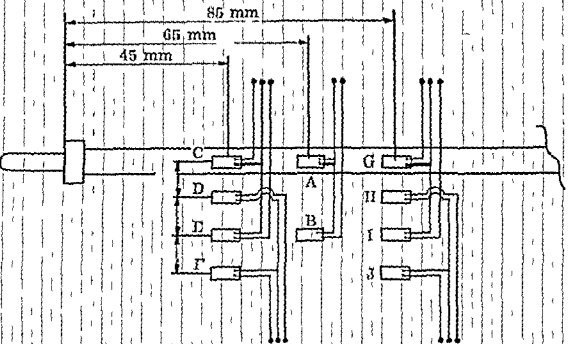


Fig 20 Distraction outrigger with gages applied



Mounting arrangement of strain gages on Harrington rod

Fig. 21 *Illustrating placement of strain gages on distraction rod*

The total stress σ_t at every point in the rod consists of three parts σ $\sigma_{b1} + \sigma_{b2}$ where σ_e is that stress due to compression from the axial load and σ_{b1} is the stress due to bending from the eccentricity of the axial load and σ_{b2} is the bending stress derived from the transverse load
To calculate these stresses, use is made of Hooke s Law

$$\sigma = E \quad \epsilon \tag{1}$$

(where E is the modulus of elasticity and ϵ the recorded strain)

$$\sigma_e = \frac{P}{\pi r^2} \tag{2}$$

$$\sigma_{b1} = \frac{P \quad a}{\frac{\pi r^3}{4}} \tag{3}$$

(where P is the axial load a the eccentricity and r the radius of the rod)
From equation 2

$$\begin{aligned} P &= \sigma \quad \pi r \\ &= \epsilon_e \quad E \pi r^2 \end{aligned} \tag{4}$$

and ϵ_e is obtained from gages A B
In order to measure the forces prior to the exposure of the posterior elements over the apical section of the curve an instrument was designed similar to the outrigger of Harrington (Zimmer No 1248) Only the axial component being desired two strain gages were mounted to each arm of the outrigger and the load computed (Perey and Lissner 1962)

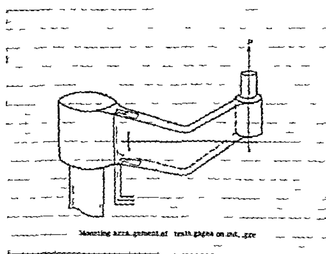


Fig 22 *Illustrating placement of strain gages on outrigger distraction device*

The distraction force P produces the desired moment Pa, a being the distance of the line of action of P from the center of the strain gages (see Fig 22)

In this theoretical consideration, the additional bending moment due to the hook is small and is ignored

$$\sigma = \frac{Pa}{\frac{th^2}{6}} \tag{5}$$

(where t is the thickness and h the height of the cantilever arm)
Substituting Hooke s law, equation 1

$$P = \frac{E\varepsilon \ th^2}{6a} \tag{6}$$

Measurements were made on a Bofors Balancing and Calibrating Unit Type BK 3 with 5 Channels and a Peekel 12 Channel Electronic Strain gage measuring bridge Type 112DA Recording was done by a Honeywell 906T Visicorder with a M100 120A Heiland Miniature Galvanometer and an ABEM Ultralette 5650 with Type 5831/N Galvanometer

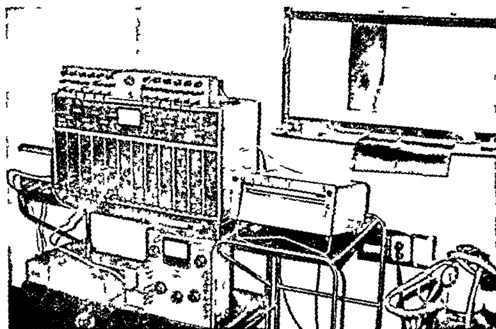


Fig 23 Electronic equipment for measuring strain (Peekel bridge type 112DA and ABEM Ultralette 5650)

CALIBRATION

Calibration of the distractor gages was carried out with hooks in place at various possible angles of the hooks relative to the instrument Because of the arrangement of strain gages on the rod however it was not essential

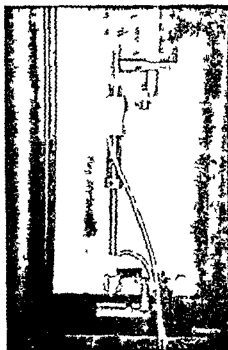


Fig 24 *Calibration of distraction outrigger in materials testing machine*

that a definite position be established and maintained with recording of th- force components A calibration curve was plotted for each device prior to insertion in the patients This was done in a materials testing machine with an inaccuracy of less than 1 % The calibration was further verified by applying weights to the hooks with the devices fixed in a rigid support Postoperative recalibration of the outrigger device indicated maintenance of accuracy

STERILIZATION

In order to avoid excessive moisture and excessive temperature a Walden autoclave was utilized In this autoclave the humidity does not exceed 1 % and the sterilizing temperature does not exceed 115 degrees C The sterilization time was 15 minutes and routine cultures of the instruments prior to insertion revealed the absence of bacterial flora (Rydell 1966)

The distraction force P produces the desired moment Pa a being the distance of the line of action of P from the center of the strain gages (see Fig 22)

In this theoretical consideration, the additional bending moment due to the hook is small and is ignored

$$\sigma = \frac{Pa}{\frac{th^2}{6}} \qquad (5)$$

(where t is the thickness and h the height of the cantilever arm)

Substituting Hooke s law equation 1

$$P = \frac{E\varepsilon \ th^2}{6a} \qquad (6)$$

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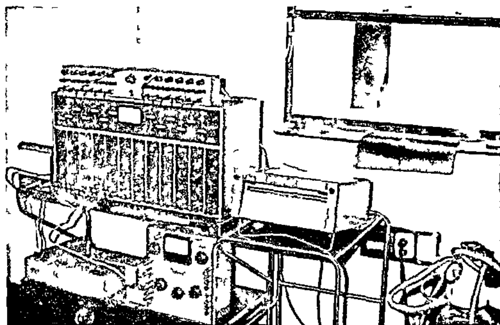


Fig 23 Electronic equipment for measuring strain (Peekel bridge type 112DA and ABEM Ultralette 5650)

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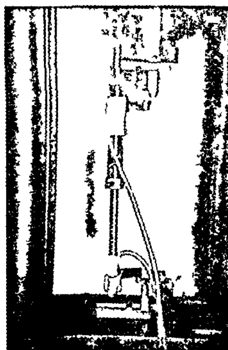


Fig 24 *Calibration of distraction outrigger in materials testing machine*

that a definite position be established and maintained with recording of the force components A calibration curve was plotted for each device prior to insertion in the patients This was done in a materials testing machine with an inaccuracy of less than 1 % The calibration was further verified by applying weights to the hooks with the devices fixed in a rigid support Postoperative recalibration of the outrigger device indicated maintenance of accuracy

STERILIZATION

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Three patients selected for intravital measurements were candidates for surgical treatment of their scoliosis by the criteria previously outlined The first patient was a 15-year old girl who continued to show progression of her scoliotic deformity, despite treatment by a Milwaukee brace Immediately prior to the surgical procedure, her erect film by the Ferguson technique measured 48 degrees and the recumbent 38 degrees (Cobb 54 and 41 degrees) and it was noted that her iliac apophyses had not completed their excursion

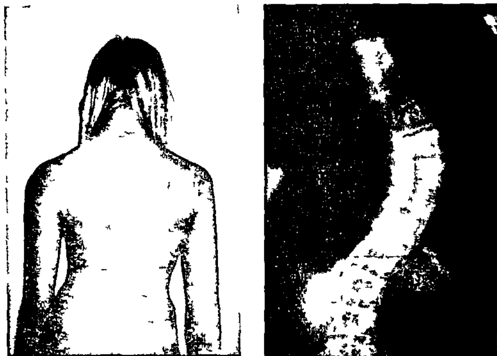


Fig 25 a b *Photograph and erect roentgenogram of Patient 1*

The second patient was a 14 year old girl whose erect curve measured 40 degrees by the Ferguson technique and 32 degrees in the recumbent view (Cobb 51 and 49 degrees) She evidenced some immaturity and the excursion of the iliac apophyses had just commenced She, too, showed evidence of progression, particularly in the four months prior to surgery The third patient was a 15-year old boy with a very severe inflexible idiopathic scoliosis Measurement of his erect film indicated a 59 degree




Fig 26 a b *Photograph and erect roentgenogram of Patient 2*

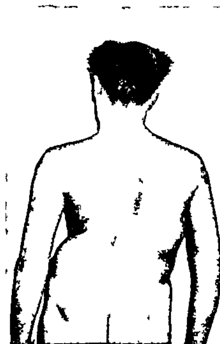



Fig 27 a b *Photograph and erect roentgenogram of Patient 3*

curvature which corrected only 5 degrees in the recumbent view (Cobb *88 and 84 degrees) This boy had manifest increased deformity in the four* months prior to surgery and by his age sex and the appearance of his apophyses, was considered to have sufficient further growth to warrant surgical correction

Prior to surgery, cardiopulmonary studies were carried out A reduction in vital capacity was evidenced in all patients On the basis of the clinical and electromyographic studies, there was no possibility of classifying these three curves otherwise than as right dorsal idiopathic scoliosis

	Erect°	Recumbent°	Extent of Curve	Vital Capacity
Patient 1	48(54)	38(41)	T6 L1	2 55/3 75
Patient 2	40(51)	32(49)	T4-T11	3 30/4 19
Patient 3	59(88)	54(84)	T5-T12	2 44/3 80

RESULTS

In the three operative procedures during which recordings were taken, every attempt was made to adhere to the established technique of spine instrumentation The safety of the patients was in no way jeopardized as a result of the study carried out



Fig 28 *Roentgenogram of distraction rod (Zimmer No 1250) with strain gages applied in situ (Patient 1)*

Patient 1 (see Fig 25 a b)

In the first patient a Harrington distraction rod with attached strain gages was inserted Continuous recordings were made during the operative procedure in the course of which the patient s curve was corrected to 20 degrees (Cobb 19 degrees) A maximal force of 18 kp was developed during the elongation of the distraction rod to the final notch It was not believed desirable to proceed further as considerable resistance was encountered at this level

An episode of coughing on recovery from anesthesia is shown in diagramatic representation of the recorded forces

During the following hours periodic recordings were made which indicated a base line of about 14 kp At one such recording during the seventh hour the patient vomited with the strain gages indicating forces up to 69 kp At 24 hours following insertion the patient was allowed to sit on the side of her bed and stand Forces up to 20 kp were recorded about 4 kp above the base line

AXIAL FORCE (KILO-PONDS) CALCULATED DURING OPERATION ON PATIENT 1

1st notch of rod	4 kp ± 2
2nd	8 kp ± 1
3rd ,	18 kp (max)
Equalized at (5)	10 kp ± 1
Hand pressure on thorax	10 kp ± 2
Recovery from anesthesia	10 kp ± 1
Coughing	37 kp (max)
Vomiting	69 kp (max)
Prior to sitting	14 kp ± 1
Sitting	18 kp ± 2
Standing	18 kp ± 2

Following these recordings the electric leads were removed and spine fusion was performed with autogenous bone at a second stage

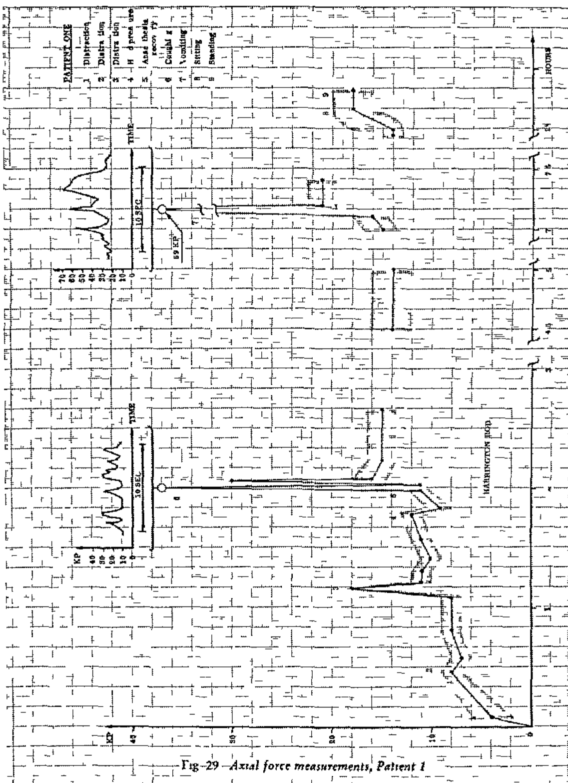


Fig-29 — *Axial force measurements, Patient 1*



Fig 30 a b *Distraction outrigger device during recording and roentgenogram showing correction (Patient 2)*

Patient 2 (see Fig 26 a, b)

In order to assess the role of the paraspinous musculature and ligaments in resisting correction, small midline incisions were used to expose the intended sites for insertion of distraction hooks at the ends of the primary curve An outrigger device was then inserted and the curve corrected by a distraction force to 28 kp

The concave and convex musculature was electrically stimulated and the resulting range of values are indicated Release of the musculature produced little alteration in the level of forces recorded and cutting the intertransverse and costotransverse ligaments caused a decrease in axial force of 1 kp

AXIAL FORCE (KILO PONDS) CALCULATED DURING OPERATION ON PATIENT 2

After outrigger correction to 10 degrees	28 kp ± 0 5
Electrical stimulation of concave erector spinae M	22 kp ± 1
Electrical stimulation of convex erector spinae M	22 kp ± 1
Following release of concave superficial and deep musculature	21 kp ± 0 5
Following release of convex superficial and deep musculature	22 kp ± 0 5
Following section of CT & IT ligaments	21 kp ± 0 5
Prior to attachment of convex compression system	31 kp ± 0 5
Maximal compression (prior to failure)	30 kp ± 0 5
At injection of celocurin (50 mg)	20 kp ± 0 8
Complete paralysis	12 kp
Lifting to bed from operating table	25 kp ± 1
Completely recovered from anesthesia	19 kp ± 0 5

By elongating the concave outrigger, the distraction force was increased to 31 kp and the Harrington compression system applied using 6 hooks Maximal tightening of the system to the point of multiple simultaneous transverse process fracture is shown

A recording distraction rod was inserted and the compression system removed Correction to 10 degrees (Cobb 20 degrees) was obtained A base line was established with the patient able to breath spontaneously, following which, a paralysing dose of celocurin was administered (50 mg) causing a significant fall in axial load at complete paralysis Following transportation to the Recovery Room the leads were removed

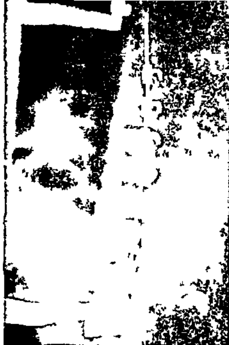


Fig 31 *Compression system application and recording f om outrigger (Patient 2)*




Fig 32 a b *Distraction rod in place prior to closure (Patient 2)*



Fig 33. *Axial force measurements Patient 2*

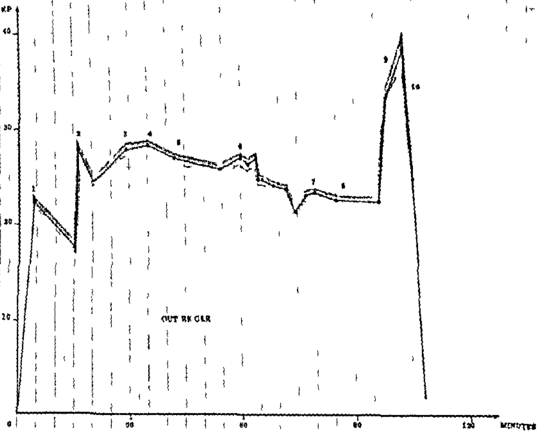


Fig. 34 *Axial force measurements Patient 3.*

Patient 3 (see Fig 27 a, b)

After insertion of the monitored outrigger device as outlined above, the axial load in this patient was slowly increased to 28 kp The concave musculature was released and the intertransverse and costotransverse ligaments cut one level at a time Releasing the apical transverse processes produced a fall of about 1 kp per level

AXIAL FORCE (KILO PONDS) CALCULATED DURING OPERATION ON PATIENT 3

Following distraction	22 kp ± 1
After 10 minutes	17 kp ± 1
Further distraction	28 kp ± 1
After 5 minutes	25 kp ± 1
Prior to release of concave musculature	28 kp ± 1
Following release of superficial & deep concave musculature	28 kp ± 1
Following section of interspinous ligaments	27 kp ± 1
Following section of CT & IT ligaments	23 kp ± 1
Following release of convex superficial & deep musculature	22 kp ± 1
Increased distraction to failure	38 kp ± 2

Release of the convex musculature is shown In an attempt to attain more correction force was increased to 38 kp The motion incident to positioning for a PA roentgenographic examination was sufficient to cause the upper hook to "cut out with immediate fall in force to zero The hook was replaced at the next higher level and a conventional distraction rod inserted Correction to 44 degrees (58 degrees Cobb) was achieved in this patient prior to spine fusion with supplemental autogenous bone

DISCUSSION

Examination of the results obtained from the three patients on whom intravital measurements were made, indicate considerably lower forces than was anticipated In view of the failure of the hook in patient 3 (Zimmer No 1253) with a load of 38 kp, it is believed that the forces measured under static extravital conditions are probably higher than can be tolerated in the body

The final axial force on the hooks as applied by the distractor tool was 20—30 kp This provided the feel of resistance mentioned by Harrington (1964)

A considerable degree of tissue relaxation was demonstrated during the

initial stages of correction A deterioration of 4 kp was noted in 10 minutes following which the force fell more slowly

Subperiosteal dissection of the paraspinous musculature, and presumably denervation (under anesthesia) did not alter the axial load to any significant degree However particularly in the third patient, selectively cutting the intertransverse and costotransverse ligaments at the apex and immediately adjacent thereto, caused a perceptible reduction of force This was only true of those ligaments at the apex No change was determined by ligamentous section at the ends of the primary curve nor was any change recorded by cutting the interspinous ligaments

Although under deep surgical anesthesia the recorded force was significantly reduced (40 %) by complete paralysis The return of spontaneous respiration was associated with the return of the axial load to the level present prior to the administration of the drug

The Harrington compression rod, using 6 hooks was found to reduce the axial load on the distraction system by about 1 kp That the amount of correctional force employed was maximal was indicated by multiple simultaneous fractures of the transverse processes

Recovery from anesthesia with the return of voluntary muscular control did not alter the recorded force However, coughing and particularly vomiting were associated with large brief increase in the force on the hooks

The action of sitting and standing were accompanied by considerable fluctuation in the recorded force but the stabilized level was only 4 kp above the base line

V Summary and conclusions

A review of the extensive literature on the etiology of scoliosis reveals a singular lack of facts on which it has been possible to develop sound hypotheses Many authors have advanced theories, some of which have been partially substantiated by animal experimentation which have been used to formulate new and presumably improved methods of treatment That these procedures have not stood the test of time has been evidenced by the still newer methods that have replaced them Such has been the rule but a few exceptions do exist

The Hibbs spine fusion, the Risser turn buckle jacket the Milwaukee brace and very few others have established a definite place in treatment Within the last few years, because of the work of Harrington and others increased attention has been directed toward improved correction of the deformity in established scoliosis There are many who would logically question the desirability of striving for a straight spine, or at least one that appears to be so, on the grounds that such attempts might endanger the vital contents of the trunk Certainly catastrophes have occurred that make mandatory a cautious approach that places the safety of the patient first and foremost However within these limits, it is believed that progress can be made and new attempts should be encouraged to improve existing forms of treatment

At the present time little is known about the etiology of idiopathic scoliosis Encouraging work is being done by Ponseti on the possible metabolic significance of the disease, and by James on the inheritance Until such time as the pathogenesis is established and can be controlled treatment will continue to depend on mechanical correction and maintenance

As the external application of force to the thorax to correct spinal deformity is mechanically inefficient, several surgeons have sought ways of increasing this efficiency by applying force directly to the spine The limiting factor however, has frequently been the strength of the attachment particularly in the thoracic area, where many surgeons performing

spinal instrumentation have had the unpleasant experience of having their carefully placed hook cut through the interarticularis Such are the problems with instrumentation that some authors in reviewing their patients, have not found their results to be improved over those obtained with conventional plaster jacket treatment

With these problems in mind, it was believed necessary to investigate the strength of conventional methods of attachment to the spine and explore other systems that might be less liable to failure In doing so a technique which used a mold of the posterior elements of methyl methacrylate was developed which proved to be significantly stronger than existing techniques as tested statically on autopsy specimens However, the toxic properties of the material are due to free monomer which is present in about 10 % concentration with temperature controlled autopolymerization (40 degrees C ± 2 degrees)

Although the amount of monomer we have used is small it was concluded that the implantation of acrylic in a child was unjustifiable In all probability, less toxic plastic materials will be developed in the future which would permit the safe use of such a technique

The limiting factor on the strength of any attachment being the area of contact a stainless steel hook was designed that closely approximated the *anatomy of the interarticularis and inferior thoracic facet* Although having only 9 % greater surface area than the largest commercially available hook, the tested strength was significantly greater It was presumed that a reduction in stress concentration due to the contour caused the difference in levels of failure

The Gruca hook, as tested was found to fail at about 55 kp ± 10 This failure occurred before the pedicle to which it would be attached in an *anterior alloplasty* procedure Because of the increase in angle or spred with failure of these hooks it was believed that this would create considerable danger to the cord Such failure could be corrected by a stronger design if it were desired to exert forces in excess of 45 kp

The application to patients of information obtained from testing specimens extravitally can only be made with considerable reservation Unfortunately no accurate measurements had been carried out of the actual force necessary to correct a scoliotic spine, nor was any information available on the role of various elements in either causing deformity or resisting correction

To accomplish these measurements electrical strain gages were employed on an outrigger device and Zimmer No 1250 rods to act as force transducers

Three patients were selected for intravital measurements who required

correction and fusion by usual surgical criteria The first two patients had flexible curves the third a resistant inflexible curve of severe degree Measurements taken during spinal instrumentation indicated that flexible curves may be readily corrected (60 % and 75 %) by forces of 20—30 kp whereas inflexible curves may be corrected only 25 % by forces of this magnitude A force of 38 kp was sufficient to cause failure of the thoracic attachment, necessitating reposition of the hook at a higher level Various releases were carried out of the posterior structures to determine whether these resisted correction In general, there was little change recorded by releasing the paraspinous musculature or interspinous ligaments In the third patient, section of the apical intertransverse and costotransverse ligaments produced some perceptible drop in force, but when this was performed on the second patient, the results were inconclusive

Complete paralysis caused a significant fall in force when compared with that present during surgical anesthesia Coincident with the return of spontaneous respiration, the axial force returned to the original level

On regaining voluntary muscle control, there was no significant change in force recorded Coughing and particularly vomiting, were associated with momentary high forces These were considerably higher than those obtained on voluntary sitting and standing

Re-examining the spinal instrumentation procedure with the information obtained from these extravital and intravital measurements it is apparent that the weak point of attachment of the distraction rod is to the thoracic spine

In view of the deterioration curve of the axial force, distraction should be attained in slow increments giving the tissues adequate time to adjust With present commercially available methods of attachment, the distraction force should not exceed 30 kp although in view of the number of patients in whom recordings were made, such an absolute figure is not significant The notches on the distraction rod (Zimmer No 1250) are 6 3 mm apart Under certain circumstances, one notch may cause a very considerable change in force levels raising the question of the desirability of having these so widely spaced This was noted in all three patients, but was particularly important in the first procedure, where the proximal notch was too little force and the distal too much

As far as determined in this study the compression system for the concave side of the curve, contributed insignificantly to reduction of the magnitude of the forces on the concave.

It is not believed possible to use the measurements obtained to either advance or negate any of the theories of the etiology of scoliosis However,

one cannot but be impressed by the small size of axial force necessary to achieve acceptable correction of the two flexible curves

Further the marked drop in force which was associated with paralysis of the intercostals raises the question of their possible role in idiopathic scoliosis

In conclusion it is believed that this study has provided a method for accurate measurement of the forces resisting correction in scoliosis as well as suggesting related forces which may contribute to the development of the deformity

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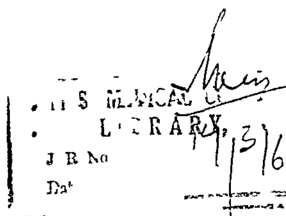
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HENRIK STØREN

Congenital Convex Pes Valgus with Vertical Talus



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Chapter I

EARLY DIAGNOSIS METHOD OF TREATMENT AND OUTLOOK WITH CLOSED REDUCTION

Chapter II

METHOD OF OPERATION AND OUTLOOK WITH OPEN REDUCTION

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In Commemoration of my Father
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Contents

Preface

Congenital convex pes valgus with vertical talus is a rare deformity which remaining untreated develops to a very troublesome and frequently disabling illness In later age palliative operations may be the *only means of treatment Treated at an early age the child can get a* normal or nearly normal foot This may be done following ways

Closed reduction (conservative treatment) described in chapter I or operative reduction described in Chapter II

Due to the infrequency of the malformation I have only a few cases which are fit to be published (Thus cases with neurological diseases are excluded) On account of the small number however it has been possible to do a more accurate observation and give a more detailed description of each individual case

I hope that some of the observations which have been made may help in the diagnosis and give directions for the treatment for this deformity and further that some of the given facts possibly may contribute to good results I also hope that these observations may be useful for comparisons with later works on this subject

CHAPTER I

Early Diagnosis, Method of Treatment and Outlook with Closed Reduction

Hohman in his book Fuss und Bein (1934) gives an extensive discussion of the congenital vertical talus in connection with what he terms der congenitte Knickplattfuss He advocates that treatment be started as early as possible in order to avoid operation similar to the principles applied in the treatment of the congenital club foot

Gunz (1939) at Hohmans clinic by autopsy of a still born child with bilateral vertical talus demonstrated that pathological changes in the tarsal joints may be present already at birth In addition contractures were so firm that extensive tenotomies and capsulotomies had to be done in order to restore normal position of the feet His case evidently represented the extreme

That conservative treatment in some cases may lead to full recovery has been demonstrated by *Hohman* (1934) and *Wainwright* (1962) However the observation of Gunz shows that full recovery cannot be expected in all cases even if the treatment is started from birth

Herndon & Heyman (1963) consider full clinical and roentgenological recovery to be very unlikely with conservative treatment In babies or very young children manipulation under anesthesia occasionally may improve the general appearance of the foot and possibly may result in fairly good function without much disability but such manipulation is unlikely to reduce the dislocation of the navicular or to improve the roentgenographic appearance of the foot appreciably — and further We now believe that if a child is seen before irreversible bone changes and contractures have developed the preferable approach is open reduction

Crice (1962) maintains that conservative treatment with reduction followed by plaster cast is usually successful in restoring satisfactory alignment and a desirable appearance of the foot in the milder form of the deformity When there is more severe deformity it is usually not possible to bring the talus out of equinus and the navicular remains on

the dorsum of the neck of the talus *William H Snyder* (1962) maintains Conservative measures are of little avail

These authors do not however state whether they have started a conservative treatment within the two first weeks after birth This may be an extremely important point in the conservative treatment but requires an early diagnosis

Pes calcaneus is no rarity in the new born and may be so marked that the dorsum of the foot easily can be brought in contact with the anterior aspect of the leg Usually this benign pes calcaneus can be corrected by the mother by exerting manual redressement during breastfeeding In some cases however contracture of the extensor tendons may be pronounced enough to necessitate redressement under anaesthesia followed by a correcting plaster cast (Case 7 and Case 9)

The sole of the foot in cases of benign pes calcaneus is usually concave or flat but may also present a convexity It is than a dorsiflexion in Choparts joint *but without a subluxation as seen by vertical talus*

Thus the term congenital convex pes valgus as used by Herndon & Heyman and others will not be correct why vertical talus may or may not be present in every case of congenital convex pes valgus (See Case 7 Figure 7 R Case 8 Figure 8 L page 19–21)

A more correct denomination is considered to be Congenital convex pes valgus *with vertical talus* and will be used in this paper

As emphasized by Herndon & Heyman the congenital vertical talus should not be confused with the vertical position of the talus seen under weightbearing in pronounced cases of the hypermobil pes planus in children and in cases of paralytic pes planus Here the navicular articulates with caput tali although with the dorsal aspect of its articular facet but there is no real subluxation of the forefoot with the navicular lying with its articular facet on the dorsal part of caput or collum tali as seen in cases named congenital vertical talus

The congenital vertical talus may immediately by the clinical examination convey the impression that it is a pes calcaneovalgus The dorsiflexion mainly taking place in the dorsal subluxated or luxated Choparts joint and that talus and in different extention calcaneus occurs in equinus is not possible clinically to make out in the newborn or in early childhood

Only the radiographs ascertains the diagnosis However in this neonatal period the evaluation of the roentgenogram is often rather difficult The ossification centre of the navicular gives no guidance until

the age of 1½–3 years or later when it becomes visible on the roentgenogram

Still the evaluation of the position of talus relative to the forefoot is possible In order to diagnose a vertical talus in an early stage and to settle the border line cases a detailed knowledge of the roentgenogram of the normal childs foot is mandatory One must also be familiar with the X ray findings in the benign congenital pes calcaneus and pes calcaneo-valgus a o To establish a basis for the early diagnosis of vertical talus a roentgenological study has been made in

I Normal feet in new born and up to early childhood
II Congenital benign pes calcaneus and pes calcaneovalgus (this transient deformity of an otherwise normal foot probably is the result of intrauterine malposition rather than a true congenital malformation)
III The common mobile pes planovalgus in children
IV A borderlinecase where the diagnosis a mild degree of vertical talus may be questionable
V Congenital convex valgus with a vertical talus in early age—conservatively treated
VI Comparison between the roentgenogram in congenital convex pes valgus with vertical talus and the rockerbottomfootdeformity seen in cases of tali pes equinovarus congenita which are under treatment

All roentgenograms in lateral view are made with the feet in the maximum possible dorsiflexion In cases where maximal dorsiflexion of different causes not is done is this mentioned
Following parameters have been used

1 *The talus axis* [1] Its angle with the longitudinal axis of tibia has been measured with the foot in maximal dorsiflexion and is named the tibiotalusangle
Its angle with calcaneusaxis is named the the talocalcanangle in lateral view Its relation to the cuboidal bone is noticed
2 *The calcaneus axis* [1] Its angle with the tibialaxis during maximal dorsiflexion of the foot is named the tibiocalcaneusangle Its relation to the cuboidal bone is noticed

---

[1] Implied the long axis

Projection variations which cause variations in angles and axes and their mutual relations are unavoidable. It should be emphasized that for this reason the evaluation of the parameters should not be too meticulous. But the accuracy is sufficient for the purpose we need in this work.

One difficulty in evaluating the talus axis at birth is the triangular or even round shape of the ossification centre during the first days, which makes the drawing of an axis questionable (Figure I Right). If a unilateral anomaly is present, comparison with the normal foot is very helpful (Figure 13).

Remarks Upon the Talus Axis and the Talocalcaneusangle in Lateral View

The usual designations "vertical talus", "talus equinus", "plantarflexed talus" a.o. are actually misleading, regarding the deformity in question. An ordinary pes equinus represents of course a plantarflexed position of talus in the ankle joint, but this is not what we here want to express. With vertical talus and the other similar designations we mean the vertical position of talus in relation to the subtalar part of the foot. In the lateral view of the radiogram this may be signified by a more vertical position of the talusaxis on the calcaneusaxis than normal, expressed by an increased talocalcaneusangle. This is frequently seen in this deformity and is then at an early age a diagnostic guide (see Figure 18, 22, 23, 24, Chapter I).

But "vertical talus" may also be seen without increased talocalcaneusangle. In most cases the reason then is an accompaning equinus position of the calcaneus. If calcaneus in relation to the verticality of talus has pronounced equinus position, the talocalcaneusangle may be smaller than normal. This is most marked by the rockerbottomfoot seen during treatment of congenital clubfoot (see Case 19, Figure 52, 53, Chapter I).

Nevertheless by congenital convex valgus with vertical talus in this material the talocalcanear angle was primarily never smaller than in normal feet.

A second cause why the enlargement of the talocalcaneusangle does not take place is seen in cases where the dorsal mobility in Chopart's joint is large and at the same time calcaneus only in a small degree or not at all follows the anterior part of the foot in the dorsal movement. In such cases the steeping of talus may be small in spite of a pro-

nounced deformity (Chapter II Case 2 Figure 8 p 82) The anatomical reason is a slack connection between calcaneus and the forefoot

Enlargement of the talocalcanear angle with normal position or only a slight steeping of the talus may be due to increased dorsiflexion of the calcaneus in cases where the achillestendon has been lengthened Parallell to this but a size larger is this seen by the pes calcaneus following paresis of the triceps suraemuscle In early childhood a wide talocalcanear angle in normal feet or in benign calcaneovalgus is caused by the physiological hypotonia of the muscles (Chapter I Figure 2 R foot Figure 5 L foot Figure 7 R foot) In older normal children (3–4 years) the angle does not change by upward pressure under the anterior part of the foot

Remarks Upon the Tibiotalus Angle in Lateral View

The anteriorly open angle between the tibia axis and the talusaxis on X ray in maximal passive dorsiflexion expresses the position of the talus If this angle here called the tibiotalus angle is wider than in normal feet we are using the term vertical talus (But implying that the position of talus really is in relation to the subtalar part of the foot) The upper limit of this angle in normal feet is in this material found to be about 105 degrees In some cases of congenital subluxation of the forefoot however we may find the tibiotalusangle to be normal This is seen in cases with hypotonia of the plantar muscles (See Case 2 Figure 8 Chapter II) Usually the dorsally dislocated forefoot will to a different extent push the talus down in vertical position (See Case 16 Figure 38 and Figure 44 A Chapter I)

I Normal Feet in New Born and up to Early Childhood

(Case 1 John G new born) *Figure 1*

Clinically normal feet Lateral view of the feet in maximal dorsiflexion In the left foot the shape of talus is well defined and the talus axis evident In the right foot talus is more pearshaped but also here the axis may be drawn with some degree of certainty The tibio talus angle is 55 degrees on the right and 80 degrees on the left side This rather great difference may be caused by more marked passiv dorsiflexion in the right ankle Some small differences in drawing of the axes must be reckoned on too The tibiocalcaneusangle is 15 degrees on the right and 35 degrees on the left foot The dorsiflexion of the calcaneus is seen to be very efficient Calcaneus during dorsiflexion essentially follows talus as demonstrated by the

talo-calcaneus angle which is 35 degrees on the right and 40 degrees on the left respectively On later control examinations the feet have shown normal development

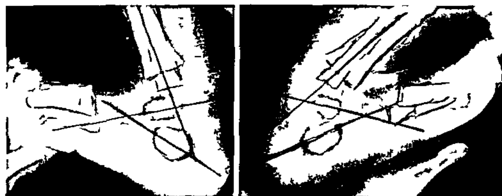


Figure 1

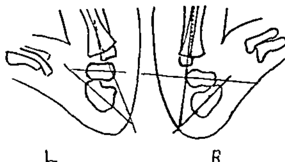


Figure 2

(Case 2 Bjorn L., aged 11 days) *Figure 2*

Clinically normal feet Lateral view Feet in maximal dorsiflexion
The tibio talus angle R 90 degrees L. 80 degrees
The tibio-calcaneus angle R 35 degrees L. 25 degrees
The talocalcaneus angle R 55 degrees L 30 degrees
The case has later shown normal development

(Case 3 Anne O., aged 5 months) *Figure 3*

Clinically normal feet which later have shown normal development Lateral view Feet in maximal dorsiflexion The ossification centres of cuboid and cuneiform I are here well developed

The tibi talus angle R 80 degrees L 85 degrees
The tibo-calcaneus angle R. 40 degrees L. 40 degrees
Talocalcaneus angle R 20 L. 30 degrees

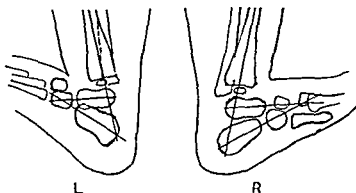


Figure 3

The talus axis is seen to pass dorsally to the cuboid on the right and through the centre of the cuboid on the left foot The more plantar course of the axis on the left foot may be caused by a stronger pressure upwards anteriorly on the forefoot on this side at X ray with a resulting slight dorsal movement in Chopart s joint This will be discussed later

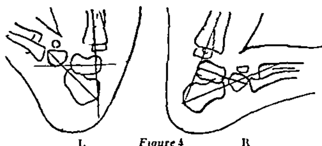


Figure 4

(Case 4 Norum A aged 5 months) *Figure 4*

Clinically normal feet which later have developed normally X ray in lateral view Feet in maximal dorsiflexion Although as old as the fore going patient the *skeleton of the foot here is smaller and the ossification centres less developed but* present in the same number

Tibio talus angle R 90 degrees L 90 degrees

Tibio calcaneus angle R 45 degrees L 35 degrees

Talocalcaneus angle R 45 degrees L 45 degrees

The talusaxis in the right foot passes through the middle of the cuboid On the left it touches the lower border of the bone This more plantar course of the talus axis in relation to the forefoot also appears to some lesser degree in both feet in the next Case 5 and is due to an increased dorsal mobility in Choparts joint This appearance is due to the hypotonia of the muscle and ligaments which is physiologically in the early age (more about this later)

The conclusion in this case is therefore Roentgenologically normal feet This is in accordance with the clinical observations and the later normal development of her feet

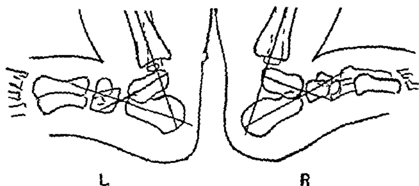


Figure 5

(Case 5 Flin T aged 8 months) *Figure 5*

Clinically normal feet X ray in lateral view Feet in maximum dorsiflexion The ossification centres of cuneiforme I and II are here both visible

Tibio talus angle R 90 degrees L 95 degrees

Tibio calcaneus angle R 40 degrees L 45 degrees

Talo calcaneus angle R 45 degrees L 45 degrees

The talus axis on both sides passes through the lower 1/4 of the cuboid The calcaneus axis cuts through the upper half of the cuboid The later development of the feet normal

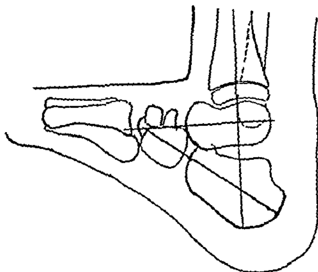


Figure 6

(Case 6 Harald B aged 5 years) *Figure 6*

Clinically normal feet Lateral view of left foot in maximum dorsiflexion The ossification centre of the navicular are here well developed

Tibio talus angle L 90 degrees

Tibio calcaneus angle L 45 degrees

Talo calcaneus angle L 35 degrees

The talus axis passes through the lower half of the navicular and touches the upper border of the cuboid The calcaneus axis goes through upper ½ of cuboid

Discussion

In six cases of clinically normal feet in children from 0–5 years of age roentgenograms in lateral view have been made of the feet in maximal passive dorsiflexion

The tibio talus angle varied from 55 degrees to 100 degrees and indicated the position of talus in the anklejoint under maximal dorsiflexion

The tibio calcaneus angle varied from 15 to 45 degrees

The talo calcaneus angle varied from 20 to 55 degrees

Calcaneus participates in the dorsiflexion simultaneously with talus and thereby the concavity of the footarch is maintained The talus axis may pass through the ossification centre of the cuboid near to its upper or lower border varying to some extent with the degree of pressure exerted under the forefoot to obtain maximal dorsiflexion as the normal hypotonia of muscles and ligaments in this young age group permits an increased dorsal movement in Choparts joint (See Figure 3 4 left foot Figure 5 both feet Figure 7 right)

II Congenital Benign Pes Calcaneus and Pes Calcaneo Valgus without Vertical Talus

(Case 7 Heidi S aged 7 days) *Figure 7*

Pes calcaneus Upon dorsiflexion the feet can be laid against the anterior aspect of the leg The right foot shows a median prominens of the tuberosity of the navicular bone and of caput tali the left shows no such prominens Both feet may be passively flexed in plantar direction to a position of 25 degrees dorsiflexion leading to a pronounced tightening of the tibialis anterior tendon Roentgenograms with maximum dorsiflexion of both feet Lateral view The ossification centre of the cuboid is here visible

Tibio talus angle R 90 degrees L 75 degrees

Tibio calcaneus angle R 30 degrees L 30 degrees

Talo calcaneus angle R 55 degrees L 35 degrees

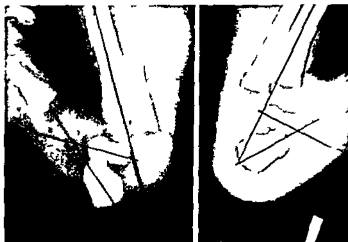


Figure 7

The talusaxis passes on the right side below while on the left side through the cuboidal ossification centre

The only treatment applied was passive stretchings exercised by the mother and both feet developed a normal appearance When the child started to walk supports were given (about this time she got poliomyelitis with paresis of muscles of the feet and arms and further control examinations have been discarded from this report)

Discussion about Case 7

The right foot shows clinical symptoms which do not exclude a congenital convex valgus with vertical talus X ray shows however no verticality of talus in the anklejoint although the talus has a somewhat steep position on relation to the axis of the calcaneus This is expressed in a quite wide talo calcaneus angle (55 degrees) Furthermore the talus axis passes below and behind the cuboid It may here be justified to suspect a mild degree of dorsal subluxation of the forefoot The evidently good result of an apparently insufficient treatment does not exclude the diagnosis A mild degree of congenital convex talus and a slight degree of dorsal subluxation of the forefoot where the verticality of the talus only refers to the calcaneus and the forefoot not to the anklejoint (About this see page 14 and 15)

The most acceptable explanation however may be that the high degree of dorsiflexion of calcaneus without a corresponding dorsiflexion of talus makes the talocalcaneus angle wide As before mentioned the cause of this and the dorsal dislocation of the cuboid is the

hypotonia of the muscles and ligaments at this age This view explains the good result of the apparently insufficient treatment but it does not explain why the right foot has a steeper position of the talus in relation to the calcaneus than the left foot A possibility of a difference uppwards pressure gives no explanation of this fact

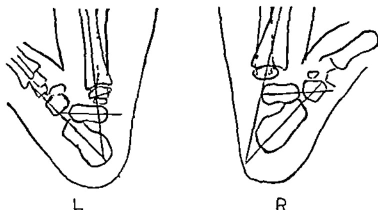


Figure 8

(Case 8 Torill S aged 12 months) *Figure 8*

Pes calcaneo valgus with slight contracture of the extensor tendons Treated with stretching exercises and supports Roentgenogram in maximum dorsiflexion Lateral view Before treatment

Tibio talus angle R. 80 degrees L. 8 degrees
Tibio-calcaneus angle R 30 degrees L 35 degrees
Talo calcaneus angle R 40 degrees L 40 degrees

The talusaxis passes just below the middle of the cuboid on the right side On the left it touches the lower border A slight rockerbottomfoot is present on the left although no verticality is seen of the talus As mentioned before (Case 3 4 and 7) the pressure under the forefoot with dorsal movement in Choparts joint is the underlying cause

Compared with the foregoing case there is in this case a normal widenes of the talo calcaneus angle i e no verticality of talus in proposition to calcaneus

(Case 9 Åse hr G aged 11 months borne 2 of February 1957)

Clinically a pes calcaneo valgus was seen with contracture in dorsiflexion of both feet At reduction under general anaesthesia the tibialis anterior and extensor digitorum longus still offered strong resistance and the tendons prominated under the skin like backstays The first attempted reduction was unsuccessful A bi lateral valgus position of the calcaneus of about 10 degrees was simultaneously corrected The contracture of the extensor tendons to the 4th and 5th toe showed several relapses and had to be treated operatively when the child was 6½ year old

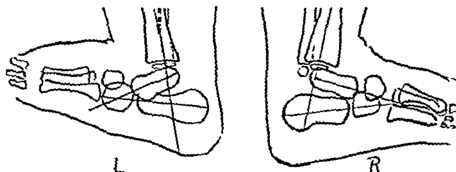


Figure 9 A

Fig 9 A X ray of the patients feet in maximal dorsiflexion in lateral view before treatment

Tibio-talus angle R 90 degrees L 105 degrees

Tibio-calcaneus angle R 70 degrees L 70 degrees

The talus axis on the right side passes in the upper border of the cuboid on the left through the middle The calcaneus axis on both sides goes just below the middle of the cuboid A dorsoplantar roentgenogram shows bilateral the forefoot in some abduction and a talo-calcaneus angle of 30 degrees (not illustrated)

In the lateral view no changes were seen after one year She wore supports for the two years and the feet developed normally except for the above mentioned contracture of the extensor tendons to the 4th and 5th toe

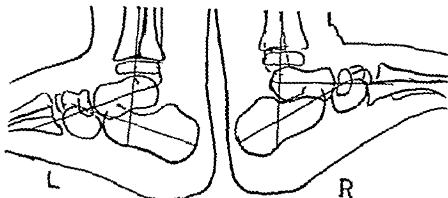


Figure 9 B

(Case 9 Ase he C aged 4 years)

X ray Feet in maximal dorsiflexion Lateral view

Tibio talus angle R 90 degrees L 100 degrees

Tibio calcaneu angle R 60 degrees L 70 degrees

Talo-calcaneus angle R 30 degrees L 35 degrees

On the right f t the talus axis goes nearly to the middle of the navicular bone centre which ha n w bee me visible This corresponds nearly to the upper border of the cub id The *calcaneus axis o n b th sides passes* just above the cuboid The longitudinal ar h f both feet is normally developed

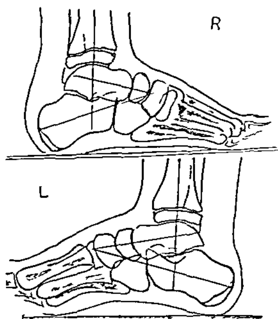


Figure 9 C

(Case 9 aged 9 years)

Clinically normal feet

X ray both feet in weightbearing normal Figure 9 C.

Summary of Case 9

The patient had congenital pes calcaneovalgus with pronounced con tractures of the tibialis anterior tendon and the extensor digitorum communis tendons The contractures were present even under general anaesthesia No vertical talus or subluxation of the navicular bone were present The contractures were treated with reduction and correction in plaster cast To the age of 11 months from the time of weightbearing supports were born for two years There was normal development of the feet both clinically and roentgenogically Last controll 9 years old Figure 9 C

III The Ordinary Pes Planovalgus in Children

(Case 10 Knut O aged 19 months)

Bilateral hypermobil pronounced pes planovalgus Feet in maximal dorsiflexion Lateral view Figure 10 A and dorsoplantar view B

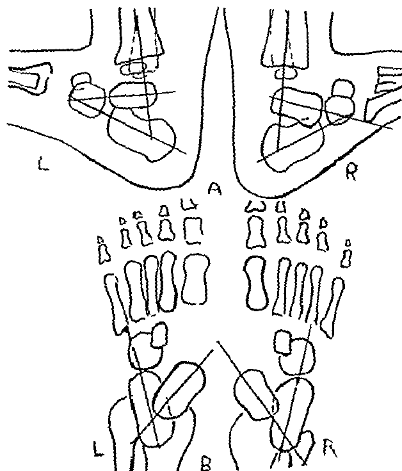


Figure 10 A and *B*

Tibio talus angle R 9a degrees L 90 degrees
Tibio-calcaneus angle R 60 degrees L 55 degrees
The talus axis on the right passes just below the middle of the cuboid on the left through the middle The calcaneus axis on the right passes just above the lower border of the cuboid on the left below the middle
The talo calcaneus angle is 3a degrees on left foot and 40 degrees on right The dors plantar talo calcaneus angle is 50 degrees on both feet

Summary of case 10

Pronounced hypermobil pes planovalgus in a 19 months old child shows without weightbearing in a dorsoplantar roentgenogram a wide talo-calcaneus angle but in the lateral view (under forced passive dorsiflexion) there is normal position of the talus and calcaneus with normal courses of corresponding axes on the left side On the right the course of the talus axis is too low The corresponding angles are normal

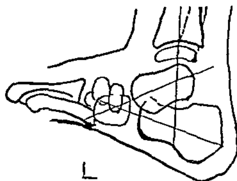


Figure 11 A

(Case 11 Bernt S aged 2 years and 8 months)

Clinically flexible pes planovalgus

Xr left foot in maximal dorsiflexion Lateral view

Tibio talus angle 105 degrees

Tibio-calcaneus angle 80 degrees

Talo-calcaneus angle 40 degrees

The talus axis cuts of the lower 1/6 of the navicular and passes dorsal to the middle of cuboid The calcaneus axis passes through the lower 1/6 of the navicular and through the upper ⅓ of cuboid

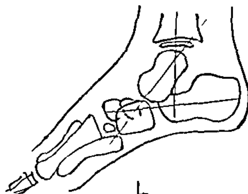


Figure 11 B

X ray the same foot in maximal plantarflexion Lateral view

Tibio talus angle 140 degrees

Tibio calcaneus angle 95 degrees

Talo-calcaneus angle 45 degrees

The talus axis cuts the lower 1 of the navicular and goes above the middle of cuboid

The calcaneus axis passes just below the middle of the navicular and goes through the upper 1/3 of cuboid

Discussion of Case 11

An ordinary hypermobil childrenflatfoot is examined X ray in lateral view without weightbearing shows in maximal dorsiflexion the wideness of the tibio talus angle at the upper limit of what we have found in normal feet As mentioned before however it will be found that in some types of congen convex pes valgus with subluxation of the forefoot we see the tibio talus angle even smaller than here (See Case 2 Figure 8 A 8 B Chapter II) But the great difference is that in those cases we have a dorsal subluxation or luxation in Choparts joint—and that don t occure in this case With exception of the tibio talus angle and tibio calcan angle the mutual relation of the axes and angles are unchanged from maximal dorsal flexion to maximal plantarflexion (*Figure 11 B*)

IV A Borderlinecase where the Diagnosis of a Mild Degree of Congen Convex Pes Valg W "Vertical Talus" may be Questionable

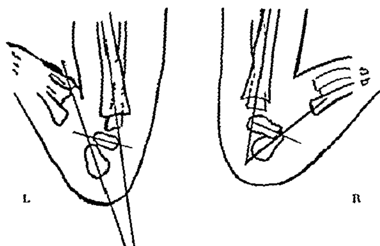


Figure 12

(Case 12 Ole F aged 4 days)

In the right foot was seen a severe degree of pes calcanevalgus with contracture of the tibialis anterior the extensor digitorum communis and the peroneus brevis tendon Caput tali prominated medially

X r tibio talus angle R 100 degrees L 80 degrees
tibio calcaneus angle R 40 degrees L 15 degrees
talo calcaneus angle R 90 degrees L 50 degrees

The talus axis in the right foot crosses the calcaneusaxis just anteriorly to the

calcaneus considerabl posteriorly and below the assumed location of the cuboid In the normal left foot the talusaxis crosses the calcaneusaxis considerably anteriorly to the calcaneus and passes through the assumed location of the cuboid Reduction was performed under general anaesthesia followed by plastercast for two weeks During the next 5 weeks redressement exercises were performed by the mother followed by plastercast for 3 weeks and then treatment with stretchings for 3 months

Both feet showed normal development

Discussion of Case 13 (Compare Case 7)

The question is if this case represents a mild degree of congenital convex valgus with dorsal subluxation in Chopart s joint of the right foot The position of talus in the anklejoint is normal but as mentioned before it is the steeping of the talus in relation to the calcaneus expressed by *the wideness of the talo calcaneus angle which decides the* diagnosis The head of talus partially covering the anterior part of calcaneus points in the same way (in accordance with the medial sliding of the head of the talus anatomically)

By imagining he location of the still invisible ossificationscentre of the cuboid we still find that the talus axis passes considerably plantar to and behind this and consequently we are allowed to conclude that the navicular lies dorsally to the head of the talus The excellent result of a minimal treatment talks against the diagnosis but does not exclude it We have too little knowledge of the effect of treatment of such border line cases at that early age (Compare Case 7 where the ossification centre of the cuboid is visible and where the circumstances are very similar to those in this case)

V Congenital Convex Pes Valgus with Vertical Talus in Early Age Conservatively Treated

(Case 13 Jon K. Borne May 9 1961 aged 7 days)

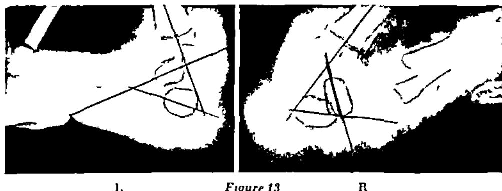
Clinically a pronounced convex pes planovalgus was found on the right side Left foot normal X ray of both feet under maximal dorsal flexion lateral view Figure 13

Tibio-talus angle R 125 degrees L 90 degrees

Tibio calcaneus angle R 75 degrees L 45 degrees

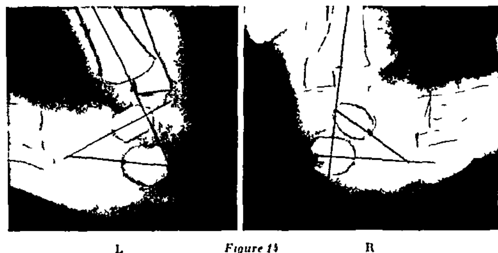
Talo-calcaneus angle R 75 degrees L 45 degrees

It is seen that on the right side the talusaxis passes very close to the anterior end of calcaneus and that talus has a rather vertical position in relation to calcaneus



L *Figure 13* R

The *calcaneus axis* on the right foot has a somewhat plantar direction while on the left it paralells the longitudinal axis of the foot Reduction was performed and corrective plastercast was applied for 7 weeks followed by stretching exercised by the mother



L *Figure 14* R

(The same ca e 13 age 5 weeks)

Figure 14 Xr in lateral view

Tibio talus angle R foot slightly reduced to 115 degrees

Tibio calcaneus angle R increased to 90 degrees

Talo calcaneus angle R reduced to 35 degrees

The cause of the increased tibio calcanear angle is here a decreased dorsiflexion in the anklejoint and the real reduction of the tibio-talus angle is in relation to this more than 10 degrees The talusaxis now passes considerably in front of the calcaneus The calcaneu axis however still points towards planta pedis That is roentgenologically a m derate degree of rockerbottomfoot is still present The normal foot is unchanged

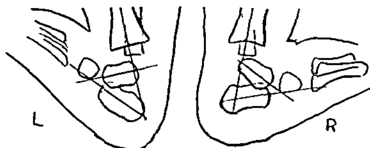


Figure 1a

(The same case 13 age 10 months)

The cuboidial ossificationcentre is now well developed

Tibio talus angle R 110 degrees L 90 degrees

Tibio-calcaneus angle R 85 degrees L 45 degrees

Talo-calcaneus angle R 50 degrees L 45 degrees

The talusaxis on both sides touches the lower border of the cuboid The calcaneus-axis on both sides touches the lower border of cuboid The patient started to walk at the age of one year and has since used supports He still displays pron unc bilateral flexible pes plano valgus When not bearing weight the feet look norma

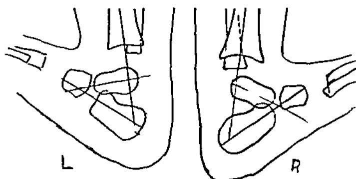


Figure 1b

(The same case 13 age 2 years)

Tibio-talus angle R 105 degrees L 95 degrees

Tibio calcaneus angle R 50 degrees L 50 degrees

Talo-calcaneus angle R 55 degrees L 45 degrees

The talusaxis on the right side touches the plantar [illegible] left the axis cuts off a small segment The calcaneus a [illegible] lower ¼ of cuboid Both feet have roentgenologicall [illegible] dinal arch

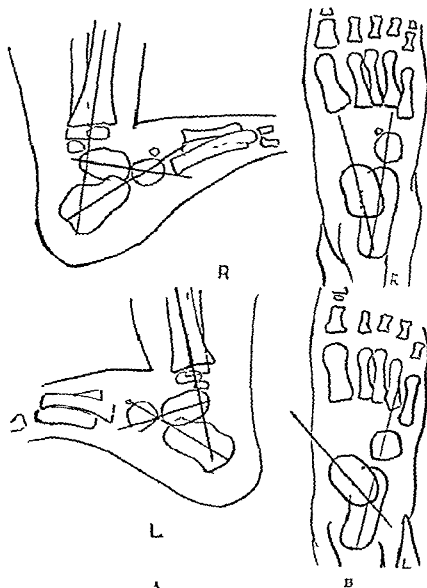


Figure 17 A and *B*

The same case (13) aged 2¾ years

Clinically a bilateral flexible pes planovalgus of moderate degree was seen. Without weightbearing the feet appeared normal.

The patient is using supports.

A. X-ray. Right and Left feet in lateral view.

B. X-ray. Right and Left feet in dorsoplantar view.

Tibio-talus angle R. 95 degrees L. 95 degrees

Tibio-calcaneus angle R. 45 degrees L. 40 degrees

Talo-calcaneus angle R. 40 degrees L. 50 degrees

The talusaxis on the right goes through the middle on the left through the lower 1/3 of the cuboid

The calcaneus axis on the right goes through the middle of the cuboid on the left through the upper 1/3

On the dorso plantar roentgenogram the talo calcanear angle is R 35 degrees L 50 degrees

Summary of Case 13

A case of clinical as well as roentgenological rightsided rockerbottom foot *with vertical talus* Conservative treatment was applied from one week after birth With minimal treatment the vertical position of talus and the equinus of the calcaneus and hereby the rockerbottomfoot was corrected Aged one year he started walking and since then used supports The patient is left with an ordinary pes planus upon weight bearing which at the age of 2¾ years is more marked on the left non treated normal foot (indicated by the large talo-calcaneus angle in dorso plantar X ray Figure 17 B)

Discussion of case 13

The roentgenological findings were clinically manifested as a rocker bottomfoot on the right and a normal concave planta on the left Thus the diagnosis of rightsided congenital convex pes valgus with vertical talus was in this case made by the following criteria

1 Clinical finding of a rockerbottomfoot

2 Tibio talus angle markedly increased

3 The talo calcaneus angle well above normal in spite of equinus of the calcaneus (Figure 13)

The talus axis passes the calcaneus axis near the anterior pole of calcaneus at the same time as the roentgenological projection of caput tali partly covers the anterior part of calcaneus (Figure 13)

Notice that the equinus of calcaneus is spontaneously recovered at the age of two years (Don t be too eager to lengthen the tendo Achilles)

Notice further that the small degree of dorsal subluxation which still was seen when the child was aged 1–2 years (see Figure 15 and 16) has disappeared on the right foot at the age of 3 years (See Figure 17 A) As this subluxation still at the age of 2 years (Figure 16) was present in the normal left foot too it is an obvious conclusion that this late subluxation on the right foot does not be a consequence of the original congenital deformity but is caused by the physiological ligamentary laxity seen at this age

Conclusion of Case 13

His rightsided congenital convex pes valgus with vertical talus is changed to a common hypermobile pes planovalgus in children with a tendency to spontaneous healing. The treatment is then supports.

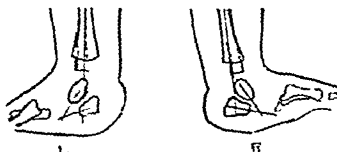


Figure 18

(Case 14. T. m H., aged 14 days. Borne April 24. 1957. *Figure 18*)

Clinical bilateral congenital rockerbottomfoot was seen. The feet may be bent upwards so the dorsum contacted the anterior aspect of the legs. The childs struggle prevented maximal dorsiflexion during X-ray examination and this has been taken into account on evaluating the pictures. Talus is elipsoid but the longitudinal axis may still be evaluated.

Tibio-talus angle R. 145 degrees L. 155 degrees.

Talo-calcaneus angle R. 40 degrees L. 35 degrees.

Both calcaneus axies points towards the plantapedis in an equinusposition. Correction was performed followed by plastercast for 14 days and later stretchings were exercised by the mother. $1\frac{1}{2}$ year old when he started to walk supports were applied. The patient was followed up for $5\frac{1}{2}$ years.

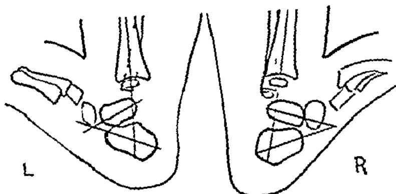


Figure 19

(The same case 14 age 10 months) *Figure 19*

Feet in maximal dorsiflexion lateral view

Tibiotalus angle R 95 degrees L 110 degrees

Tibio calcaneus angle R 60 degrees L 70 degrees

Talo calcaneus angle R 35 degrees L 45 degrees

Talusaxis on the right goes through the lower 1/ of cuboid on the left plantar to the cuboid i e a steeping verticality of the talus is still present on the left foot and a dorsal subluxation of the forefoot is present on both feet although more pronounced on the left

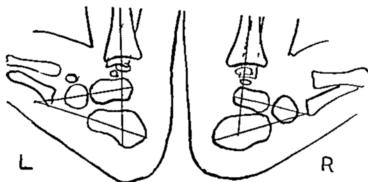


Figure 20

(Case 14 May 27 1958 age 15 months) *Figure 20*

Tibio talus angle R 95 degrees L 95 degrees

Tibio calcaneus angle R 80 degrees L 75 degrees

Talo calcaneus angle R 30 degrees L 25 degrees

The talus axis passes on both feet near the middle of cuboid

Calcaneus axis passes on right foot the lower border of cuboid on left foot it passes below the cuboid

Conclusion

Bilateral at this time no vertical position of talus but the calcaneus axes have still some degrees of plantar direction The subluxation of the forefoot is not pronounced as seen half a year ago

(Case 14 age 5½ years) *Figure 21*

Feet in maximal dorsiflexion Lateral view

Tibio talus angle R 90 degrees L 90 degrees

Tibio calcaneus angle R 60 degrees L 60 degrees

Talo calcaneus angle R 30 degrees L 25 degrees

The talusaxis on both feet passes near the middle of the ossification centre of the navicular which has now become visible on the roentgenogram It further passes

well dorsal to the cuboid The calcaneusaxis goes through the middle of the cuboid I e all roentgenological findings are normal (see Figure 6 page 18 which shows a normal foot to the same age)

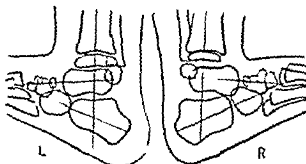


Figure 21

Summary of Case 14

Bilateral congenital convex pes valgus with vertical talus treated conservatively with reduction at the age of 14 days followed by plaster cast worn for 14 days Later stretchings exercised by the mother Supportive soles when he started to walk at the age of 1½ year Control examination at the age of 1½ year shows normal feet

Discussion of Cases Cured in Spite of a Short Conservative Treatment

Cases 12-13-14 all show a complete clinical and roentgenological healing of their congenital convex valgus with vertical talus by only a minimal treatment Owing to this the diagnosis may be questioned The diagnostic facts have consequently been particulary discussed in each case

Case 12 is characterized as a borderline case which is considered as mild

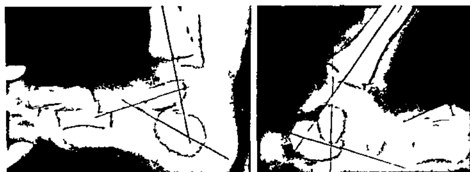
Case 13 shows criteria of having a more pronounced deformity In case 14 the shapes of the bonecentres of talus and calcaneus are irregular and the reliability of the axes may be questioned But the X rays shows later a conspicious subluxation of the forefoot as late as the age of 10 months (Figure 19)

The common characteristic of these three cases is the reduction taking place in the first days after birth The reason why a more pronounced case as case 13 is cured by a minimal conservative treatment when other cases of apparently the same degree needs a pro

tracted thorough treatment in spite of an early start may be the great anatomical variations in this deformity even though the outward appearance is the same



A Rightsided rockerbottomfoot
B Notice the pronounced abduction contracture on the right foot
C Medial projection of caput tali on right foot



L *Figure 22* R

(Case 15 Kjersti A age 4 days October 29 1962)

Clinically a rightsided convex pes valgus with contracture of the tibialis anterius peroneus brevis and the toe extensor tendons There was a pronounced abduction of the forefoot (Figure 22 A B C) The left foot was normal

X ray Lateral view in passive maximal dorsiflexion The cuboidal ossification center is allready visible (Figure 22 D)

Tibio talus angle R 150 degrees L 90 degrees

Tibio calcaneus angle R 80 degrees L 45 degrees

Talo calcaneus angle R 85 degrees L 40 degrees

The talusaxis on right side crosses the anterior part of calcaneus Caput tali covers the upper aspect of this part The calcaneusaxis goes plantar to cuboid pointing towards the planta pedis (corresponding with the rather large lateral tibiocalc angle) The left side is clinically and roentgenologically normal

Treatment started at once with reduction under anaesthesia and following plastercasts

well dorsal to the cuboid The calcaneusaxis goes through the middle of the cuboid I e all roentgenological findings are normal (see Figure 6 page 18 which shows a normal foot to the same age)

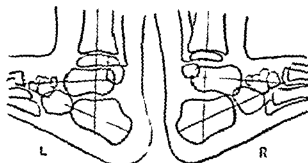


Figure 21

Summary of Case 14

Bilateral congenital convex pes valgus with vertical talus treated conservatively with reduction at the age of 14 days followed by plaster cast worn for 14 days Later stretchings exercised by the mother Supportive soles when he started to walk at the age of 1½ year Control examination at the age of 5½ year shows normal feet

Discussion of Cases Cured in Spite of a Short Conservative Treatment

Cases 12-13-14 all show a complete clinical and roentgenological healing of their congenital convex valgus with vertical talus by only a minimal treatment Owing to this the diagnosis may be questioned The diagnostic facts have consequently been particulary discussed in each case

Case 12 is characterized as a borderline case which is considered as mild

Case 13 shows criteria of having a more pronounced deformity In case 14 the shapes of the bonecentres of talus and calcaneus are irregular and the reliability of the axes may be questioned But the X rays shows later a conspicious subluxation of the forefoot as late as the age of 10 months (Figure 19)

The common characteristic of these three cases is the reduction taking place in the first days after birth The reason why a more pronounced case as case 13 is cured by a minimal conservative treatment when other cases of apparently the same degree needs a pro

made with the foot in 90 degrees position The cuneiform ossificationcentre is no visible

X ray (Figure 23 B)

Tibio talus angle R 95 degrees

Tibio-calcaneus angle R 70 degrees

Talo-calcaneus angle R 25 degrees

The talusaxis goes dorsally to the upper cuboidal border

The calcaneusaxis passes the dorsal ½ of cuboid

The longitudinal arch of the foot is concave *I e* on control examination at age 3½ months the foot *appears clinically as well as roentgenologically normal—after treatment with closed reduction* followed by pastercast fixation from 4 days after birth

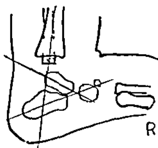


Figure 24

(Case 15 Kjersti A, February 27 1963 age 4 months)

A small slip was felt at the moment of careful dorsiflexion The picture was taken with approximately 10 degrees dorsiflexion of the foot and demonstrates that the tibio talus angle has increased to 110 degrees in spite of the increased dorsiflexion of the foot as compared to that on Figure 23 The talusaxis goes now near the lower border of the cuboid the calcaneusaxis passes above the middle part The talo-calcaneus angle has increased from 30 degrees to 50 degrees

I e an imminent relapse is indicated by the roentgenological findings increased tibio talus angle talo-calcaneus angle and the low passage of the talusaxis The cause of the relapse is supposed to be the passive dorsiflexion prematurely made

A corrective plastercast was again applied

(Case 15 April 10 1963 6 weeks later treated with plastercast) *Figure 25*

The right foot in 10 degrees dorsiflexion The roentgenological signs of an imminent relapse as described in Figure 24 have disappeared

Tibio talus angle R 90 degrees

Tibio calcaneus angle R 70 degrees

Talo-calcaneus angle R 30 degrees

The talusaxis passes above the cuboid the calcaneusaxis through the upper half of the cuboid On the *dorsoplantar* view the *talo-calcaneus angle is approximately*

10 degrees (which is less than 1/3 the normal value however no adduction of the forefoot is present) *I e* the axes and the angles of the foot on the lateral view are normal The plastercast was now omitted

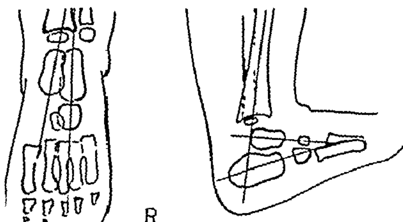


Figure 25

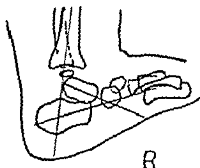


Figure 26

(Case 15 June 12 after 2 months without plastercast) *Figure 26*

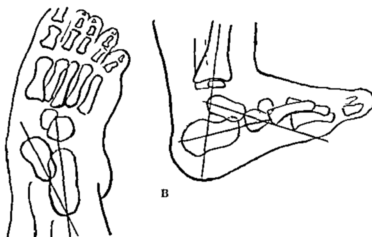
Right foot in the same dorsiflexion as in Figure 25 X ray in lateral view The tibio talus angle has increased to 105 degrees while the tibio calcaneus angle is unchanged (70 degrees) The talusaxis again goes near the lower border of the cuboid as does the calcaneusaxis The condition is very like to that before the last plastercast was applied (Februar 27 1963 see Figure 24) However a plastercast was not applied on this occasion although a relapse was obviously threatning as judged by the roentgenological findings

(Case 15 August 8 1963 age 9 months)

Clinically a normal footarch by pressing the foot against the ground representing an attempt to replace weightbearing (why she not still has commenced standing) Figure 27 A



A



B

Figure 27 A and *B*

Figure 27 *B* Radiography of the right foot in dorsiflexion 10 degrees as in fore going figures

Tibio talus angle R 100 degrees

Tibio-calcaneus angle R 70 degrees

Talo-calcaneus angle R 30 degrees

The talusaxis passes above the middle of the cuboid the calcaneus axis just below the middle X ray in dorsoplantar view demonstrates a considerable ab duction of the forefoot

The talusaxis passes considerably medial to the basis of the 1th metatarsal but in spite of this the talo calcaneus angle is only 25 degrees *The reason is the adduction position of calcaneus and the abduction taking place in Choparts joint—not in the subtalar joints as the case is in an ordinar pes planovalgus*

(Case 15 September 9 1963 10 months of age)

Clinically the abduction of the forefoot and the contracture persist The head of the talus is prominating medially Upon weightbearing the longitudinal arch of the foot sinks resulting in a considerable planovalgus X ray lateral view Figure 28 A

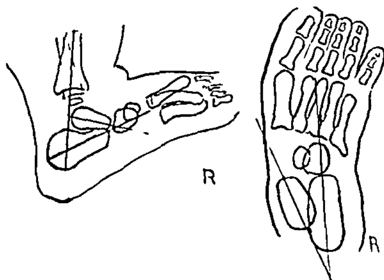


Figure 28 A

Tibio talus angle R 95 degrees

Tibio-calcaneus angle R 60 degrees

Talo calcaneus angle 40 degrees

The talus and calcaneus axes both goe below the middle of the cuboid. On the *dorsoplantar* roentgenogram the talo calcaneus angle has increased during one month from 20 degrees to 40 degrees. Under general anaesthesia redressement was now done of the contracture and a plastercast was applied extending above the knee.

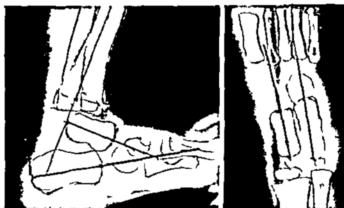


Figure 28 B

(Case 15. October 23. 1963). *Figure 28 B*

Shows the situation after reduction and treatment with plastercast for 6 weeks. The foot can now tolerate a dorsiflexion of more than 15 degrees which is demonstrated by

Tibio talus angle R 90 degrees

Tibio calcaneus angle R 60 degrees

The talo calcanneus angle 30 degrees (10 degrees diminished in relation to the foregoing X ray 6 weeks ago) The talusaxis passes dorsally to the cuboid The dorsoplantar roentgenogram now demonstrates that the talo calcaneus angle is zero and the axis of the foot is straight A plastercast was applied for another 6 weeks followed by supports made after a carefully molded cast

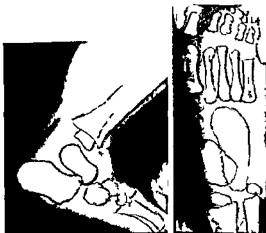


Figure 28 C

(Case 15 December 16 1963 6 months later) *Figure 28 C*

Clinically both feet appear normal Roentgenogram of right foot in 15 degrees of dorsiflexion lateral view (The unchanged X ray of the normal left foot does not here be repeated)

Tibio talus angle R 90 degrees L 95 degrees

Tibio-calcaneus angle R 55 degrees L 60 degrees

Talo calcaneus angle R 35 degrees L 30 degrees

The talusaxis on the right foot cuts off the upper 1/3 of the cuboid on the left the same

The calcaneusaxis on the right goes near to the lower border of the cuboid on the left a little above the middle

Dorsoplantar X ray shows a small tendens to abduction The talo calcaneus angle of 30 degrees shows that the abduction partly takes place subtalo as by an ordinary flatfoot The plastercast is now omitted and she starts wearing the supports

(Case 15 Kjersti A March 18 1964) *Figure 29 A*

She has worn supports since her plastercast was omitted 16 12 63 12 weeks ago Her mother has observed that her right foot is ever more ill looking

There is now during weightbearing a medial prominens of the head of talus X ray right foot in *lateral* view and dorsiflexion 5 degrees shows

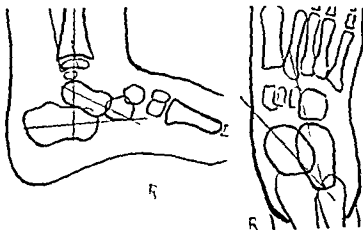


Figure 29 A

Tibio talus angle R 115 degrees

Tibio calcaneus angle R 85 degrees L 40 degrees

Talo-calcaneus angle R 30 degrees

The talusaxis passes the lower 1/3 of cuboid X ray in dorsoplantar view shows a pronounced medial direction of the talusaxis (in spite of a talo calcaneus angle of 30 degrees) and the forefoot shows an increased abduction Conclusion Clinically and roentgenologically an incipient relaps

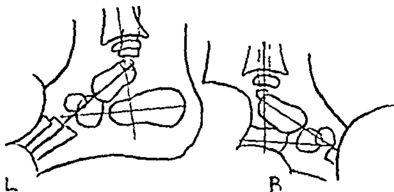


Figure 29 B

(Case 15 Kjersti V., at the same time)

X ray in anaesthesia The forefoot is adducted pronated and flexed in plantar direction and a press upwards is done under the anterior part of calcaneus (The plantarflexion in the ankle is in this position here ca 20 degrees)

We are seeing how the subluxation in this position is quite corrected The criterium for this is the passing of the talusaxis near by to the dorsal border of cuboid (Cfr X ray of the normal left foot) The child got plastercast in corrected position

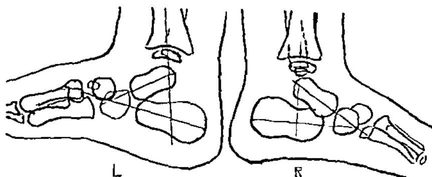


Figure 30

(Case 15 Kjersti A April 29 1964 Age 2 years and 2 months)

X ray right foot in lateral view in 5 degrees plantarflexion She had her plaster cast from March 18 1964 (6 weeks) X ray shows that her foot can stand a correction from the stronger equinus to this position without reluxation of the forefoot

Criteria for this by judgement of the picture are

1 Talus axis is dorsal to the middle of cuboid

2 Talo calcaneus angle is unchanged 30 degrees

The reason why the tibio talus angle on right foot is 120 degrees is of course that the anklejoint on this side instead of being dorsiflexed is 5 degrees plantar flexed Compared to the normal left foot which is radiographed in 10 degrees dorsi flexion and shows a tibio talus angle of 105 degrees the real position of talus at the right foot is nearly to the same as on the left

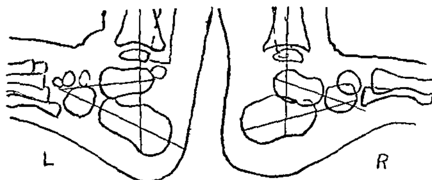


Figure 31 A

(Case 15 Kjersti A September 23 1964 age 2½ years) *Figure 31 a* and *B*

The preceding examination 5 months ago The early 3 of these months she had a walking plasterbandage and the last 2 months she had supports

Clinically Both feet shows flatfoot by weightbearing Without weightbearing a normal longitudinal arch

X ray right and left foot in lateral view in dorsiflexion 10 degrees The navicular centre is now visible on the left foot

Tibio-talus R 105 degrees L 95 degrees

Tibio-calcaneus R 80 degrees L 60 degrees

Talo calcaneus R 35 degrees L 35 degrees

The talusaxis passes now cuboid below the middle (on the left foot it touches the dorsal border)

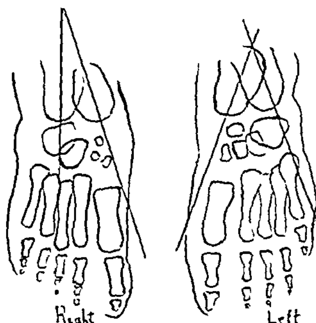


Figure 31 B

(At the same time)

X ray both feet in dorsoplantar view

Talo-calcaneus angle R 30 degrees L 40 degrees

Discussion

Clinically we have now on both feet a picture like that by hypermobile children flatfoot

The small degree of dorsal sliding in Chopart's joint seen by passive dorsiflexion on X ray in lateral view is as to be remembered seen by flexible flatfoot in childhood too (see Figure 10 Case 10 P 24)

The proportionally small dorsoplantar talo calcaneus angle seen at the right foot is as mentioned before due to the adduction position of the calcaneus in this deformity

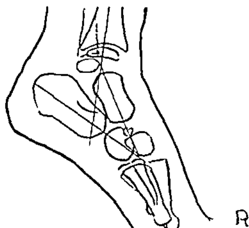


Figure 32 A

(Case 15 Kjersti A November 1964) She has now used her supports for 4 months

X ray right foot in plantarflexion 150 degrees

The navicular centre is now visible on the right foot too In this position there is as expected full reduction! The talusaxis is going dorsally to cuboid and through the navicular The talo calcaneus angle is in this position decreased to 25 degrees The calcaneus axis goes nearly to the middle of the cuboid

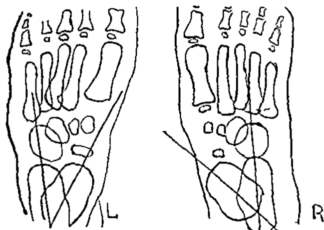


Figure 32 B

The dorsoplantar talo calcaneus angle is increased to 45 degrees (Left 35 degrees)

X ray right and left foot in lateral view in dorsiflexion 10 degrees The navicular centre is now visible on the left foot

Tibio-talus R 105 degrees L 95 degrees

Tibio-calcaneus R 80 degrees L 60 degrees.

Talo-calcaneus R 35 degrees L 35 degrees

The talusaxis pa es now cuboid below the middle (on the left foot it touches the dorsal border)

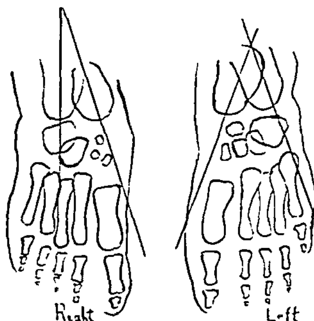


Figure 31 B

(At the same time)

X ray both feet in dorsoplantar view

Talo-calcaneus angle R 30 degrees L 40 degrees

Discussion

Clinically we have now on both feet a picture like that by hyper mobile children flatfoot

The small degree of dorsal sliding in Chopart s joint seen by passive dorsiflexion on X ray in lateral view is as to be remembered seen by flexible flatfoot in childhood too (see Figure 10 Case 10 P 24)

The proportionally small dorsoplantar talo-calcaneus angle seen at the right foot is as mentioned before due to the adduction position of the calcaneus in this deformity

Figure 33 B

Dorsoplantar talo-calcaneus angle 40 degrees
The abduction located to the Choparts joint is corrected But it is a wide talo calcanear angle due to a *subtalar* abduction as by an ordinar hypermobile flatfoot in children

Some Reflexions on the Lengthening of the Achillestendon

Comparisons of the X ray 31 A before lengthening of the achilles tendon with X ray after lengthening (Figure 33 A) shows no tangible differences The only new thing found is a more dorsal directed calcanear axis relatively to the forefoot Because of this the longitudinal arch is a little more accentuated This appearence is identically with the increasing of the arch following the pes calcaneus we may see by informity of the triceps suraemuscle (f inst by paresis) and that does not represent a real reinforcement of the arch (see Chapter I Case 15 Figure 35 C Case 16 Figure 50 L) Due to the lesser resistance of the triceps surae the dorsiflexion in the anklejoint has increased but the in lateral view not changed talo-calcanear angle proves that the mutual relation between the talus and the calcaneus in this case are unchanged (In other cases of similare conditions appears enlarging of the talo-calcanear angle See page 14 "Remarks about the talocalcanear angle) This is in accordance with experiences later mentioned in this paper (see Chapter II Case 1 page 79) where lengthening of tendo ach did not be indicated although the lengthening before the operative correction had been deemed inavitable In consequence of these reflections I do not be quite convinced of the necessity of the lengthening of the tendon made in right foot Case 15

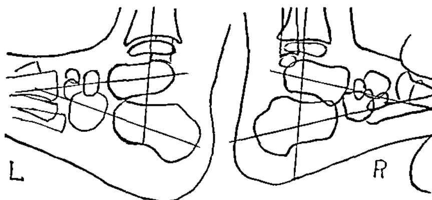


Figure 34 A

(Ca e 15 Kjersti A October 5 196) age 3 years and 7 months) *Figure 34 A*

She has walked with her supports

Clinically without weightbearing the footarch is normal With weightbearing the footarch in some degree sinks down There is too some degree of abduction of the forefoot

X ray Tibio talus angle R 95 degrees The normal L 95 degrees.
Tibio-calcaneus angle R 65 degrees The normal L 65 degrees
Talo-calcaneus angle R 30 degrees The normal L 30 degrees

On right foot the talusaxis passes the lowest 1/3 of the navicular and the upper edge of cuboid There is no subluxation of the forefoot and no steeping of talus

I e X ray right foot in maximal dorsiflexion lateral view—as on a normal foot (compare left foot on the same picture)

X ray in dorsoplantar view right foot shows a slight abduction of the forefoot and a narrow talo-calcaneus angle (15 degrees) The talusaxis has a somewhat medial course and the calcaneusaxis has relative hereto some medial direction too (This picture is not represented here)

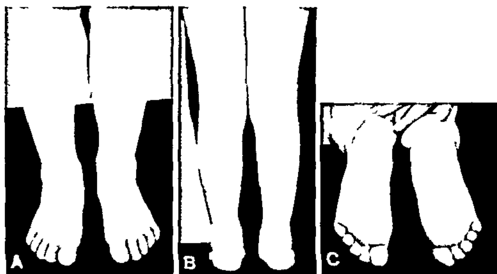
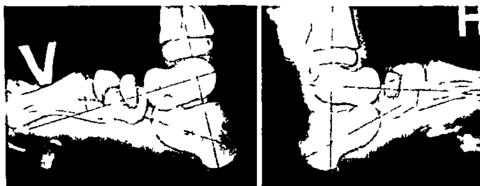


Figure 35 A

(Case 15 Kjersti A May 10 1966 aged 4¾ years)

Last examination 7 months ago She is wearing supports but they are now a little to small Due to the Achilleslengthening the right leg is considerable thinner than the left there is a tendency to pes calcaneus and the dorsiflexion is in some degrees wider than on the normal left foot The right foot is smaller and the forefoot is abducted but the abductionposition sitting in the Choparts joint is reducible without anaesthesia—no valgus of the heels (Figure 35 A a b c)



L *Figure 35 B* R

(Case 15 Kjerstí A May 10 X ray lateral view both feet in maximal dorsiflexion)

Right foot Tibio talus angle 90 degrees Left 90 degrees
Right foot Tibio calcaneus angle 50 degrees Left 50 degrees
Right foot Talo calcaneus angle 30 degrees Left 35 degrees

The talusaxis passes the lower 1/6 of navicular and the upper half of cuboid on both feet The calcaneusaxis passes the lower half of cuboid With the exception of small differences owing to the slight variations in the roentgenological projections —which are not possible to prevent —show the X rays of the right and the left foot now a marked resemblance



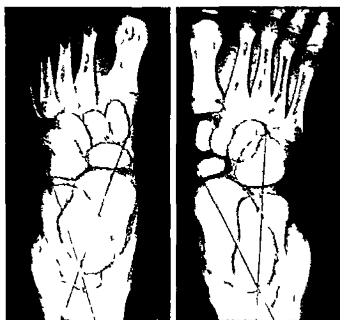
L *Figure 35 C* R

(Case 15 at the same time X ray both feet in lateral view *in weightbearing)*

Right foot shows a tibiotalus angle in 120 degrees The position of the ankle is then 90 degrees The tibio talus angle by maximal dorsiflexion (10–15 degrees) will then be about 105–110 degrees Left foot have an ankle position of 10–15 degrees dorsiflexion and shows a tibio calcaneus angle of 100–105 degrees The tibio calcaneus angles are on the same reason 95 degrees on the right and 80 degrees on the left foot That talus on the right side has no real steeping is signified by the talo calcaneus angles which on both feet are 45 degrees

Further the talus axis passes on both sides the lower of the navicular On the

right foot is the navicular bone in its whole extention projected on cuboid at the left side it is partly projected onto the roentgenological circumference of cuboid The cause of this might be some difference in the roentgenological photographic rightsetting But the projection in the other parts of the photographs of right and left foot are very homogeneous In all probability the reason then must be the *sinking down of the navicular* as we see it in an ordinary flatfoot—and which is here the cause of the abrogation of the footarch contrary to the occurrence by cong convex pes valgus with vertical talus where the *dorsal subluxation* of the forefoot in Choparts joint is the cause of the flattening or in more pronounced cases the rockerbottomfootposition



L *Figure 35 D* R

(Case 15 X ray in dorsoplantar view shows the abduction of the forefoot in Cho part s joint on right foot)

The talo calcaneus angle is only twenty five degrees although we have some medial deviation of the talusaxis The cause of this is as earlier in this paper frequently maintained the adduction of the calcaneus which has been clearly demonstrated

The only remainder of her primary congenital deformity is now the abduction position of the forefoot while the dorsal subluxation of her forefoot in Chopart s joint—her congenital convex pes valgus with vertical talus—is considered to be healed or changed to an ordinary flatfoot

Summary of Case 15

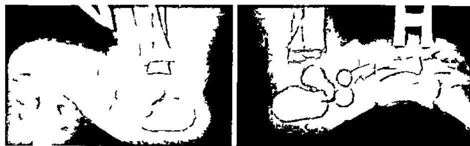
Rightsided congenital convex pes valgus with vertical talus is treated with closed reduction in anaesthesia and followed by plastercast from the age of 4 days X-rays showed normal proportions of the bone centres continually after 3½ month But when the plastercast at that time prematurely was omitted and likely too caused by an incautious passive dorsiflexion of the forefoot symptoms of relapse appeared New casts were applied This was repeated over and over again because of a threatening relapse also at the time when the child began to walk with supports

One of the components of the deformity the abduction contracture in Chopart s joint showed a particular tendency to relapse This abduction contracture in Chopart s joint is not to be confounded with the abduction contracture which takes place in the subtalar joints in an ordinary flatfoot

Examination of the child aged 3 years and 7 months shows clinically the picture of a hypermobile children flatfoot Roentgenologically without weightbearing we find a normal foot Examination at the age of 4¼ year shows clinically an abduction contracture of the forefoot which can be corrected without anaesthesia On weightbearing there is a flattening of the footarch

X-ray in lateral view without weightbearing shows a quite normal foot With weightbearing there is no real steeping of talus and no dorsal subluxation of the forefoot but the picture of an ordinary flat foot

This and the tendency to abduction contracture in Chopart s joint still has to be treated with supports (or orthopedic shoes) and physiotherapy (manual corredtions of the abduction contracture and adjusted exercises)



L *Figure 36* R

(Case 16 Ann Cun H., borne February 23 1962)

First examination May 1962 near 3 months old

Bilateral pronounced rigid rockerbottomfoot (see Chapter II Case 4 Figure 16 a b c d X ray Figure 17 page ?? 93)

Medial prominens of the caput tali and with abduction of the forefoot (Left foot where it was necessary to do an operative reduction is treated of in Chapter II as Case 4 — In cause of the comparison will right foot in that chapter be partly described parallell to the operated too)

X ray May 16 196? Figure 36

Tibio-talus angle R 170 degrees L 17? degrees

Tibio calcaneus angle R 10 degrees L 10? degrees

Talo calcaneus angle from side R 45 degrees L 55 degrees

The talusaxis in the both feet cuts the upper anterior aspect of the calcaneus

The right calcaneusaxis goes through the lower border of cuboid while the left axis passes slightly above the border *I e* There is roentgenologically a moderate equinus position of the calcaneus The deformity is roentgenologically more pronounced in the left foot Attempt at correction under generel anaesthesia was at once done on both feet followed by fixation in plastercast in a position attained as near to a corrected position as possible However for 15 weeks repeated attempts of reduction were made and following plastercasts were applied without success The deformity remained uncorrected Figure 37 September 2? 196?

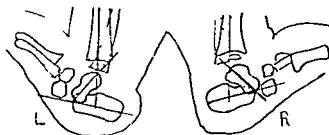


Figure 37

The same treatment was never the less continued for another 3 months thus giving a total time of treatment of 6½ months

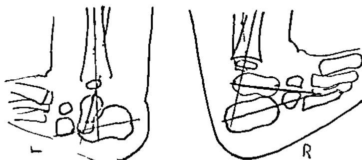


Figure 38

(Case 16 December 19 196? The child was then 10 months) *Figure 38*

Demonstrates that the *right talus now has achieved a normal position* while th left talus is unchanged The plastercasts was n w tentatively omitted on the righ foot and control 4 m nths later showed the foot still normal

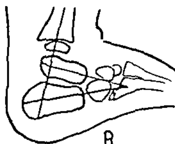


Figure 39

(Case 16 April 24 1963 The child now 14 months) *Figure 39*

The tibio talus angle is 90 degrees The talo calcaneus angle is 25 degrees Th talusaxis touches the upper border of the cuboid while the calcaneusaxis cuts of th lower ¹ of the bone The minor difference in the axes as compared to Figure 38 is caused by a slight difference in projection as demonstrated by the differen position of the metatarsal bones

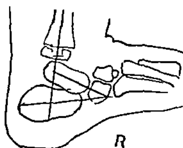
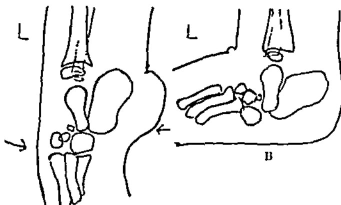


Figure 40

(Case 16 June 5 1963 Age 15 months X ray in 10 degrees dorsiflexion of the ankle)

Now after 9 months without the plastercast the tibio talus angle is seen to hav increased from 90 degrees to 100 degrees The talusaxis goes through the middle o the cuboid The calcaneus axis goes through the lower part of the cuboid as before but still more plantarly i e There are signs of threatening relapse Therefore a pla ter ast is anew applied on the right foot

On the l ft foot attempts of closed reduction still were made Figure 41 A and B 1 ws X ray made during the reduction manipulations in the last attempt The erior part of calcaneus is pressed dorsally the forefoot just distal to the Ch part s joint is pressed plantarly with the foot kept in maximal equinus



A *Figure 41 A and B*

Why no closed reduction succeeded open reduction on the left foot had to be performed on July 30 1963 (See Chapter II Case 4 page 92)

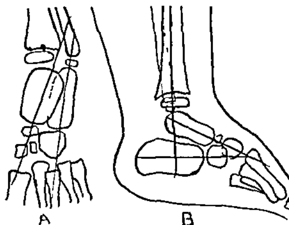


Figure 42

(Case 16 August 21 1963 Age 18 months)

X ray Right foot in 15 degrees plantarflexion lateral view Dorsal flexion was avoided at this moment The ossification center of the navicular is visible

Tibio talus angle R 105 degrees (When corrected for the plantarflexion in the ankle 105 degrees — 15 degrees = 90 degrees)

Tibio calcaneus angle from side R 85 degrees (When corrected for the plantar flexion 85 degrees — 15 degrees = 70 degrees)

Talo calcaneus angle 30 degrees

The talusaxis passes over the cuboid and just through the plantar part of the navicular The calcaneus axis goes just below the middle of cuboid Figure 42 B The dorsoplantar talo calcaneus angle 10 degrees Figure 42 A

Plastercast was applied

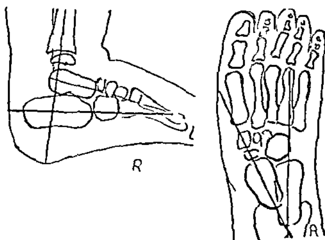


Figure 43

(Case 16 September 18 1963 Age 19 months)

After another month in plastercast dorsal flexion to 90 degrees was carefully done

Tibio talus angle R 95 degrees

Tibio-calcaneus angle R 85 degrees

Talo calcaneus angle 20 degrees

The talusaxis passes over the cuboid but touches the lower navicular border The calcaneus axis goes below the middle of the cuboid In the dorsoplantar view the talo calcaneus angle is 35 degrees and there is a slight tendency towards abduction of the forefoot The relation between the talusaxis and the navicular indicates a tendency to dorsal subluxation and the foot was therefore immobilized in plastercast with the forefoot in plantar flexion adduction and pronation The cast was removed from both feet on November 6 1963 for control examination (roentgenogram did not be made) Both feet looked nearly normal but on the right there was a slight abduction of the forefoot and some slight medial pro minens of the head of talus A new plastercast extending above the knee was applied on both feet after a plastermould for the making of supports had been made

(Case 16 December 18 1963 Age 22 months)

Plastercast removed Clinically before roentgenography both feet look good Roentgenogram with slight dorsiflexion lateral view *There is complete re dislocation on right foot* The navicular ossificationcenter is lying upon the dorsal aspect of caput tali Talus is pressed into a vertical position of 170 degrees by the dorsally dislocated forefoot The head of talus has also been dislocated medially to calcaneus (There was no doctor present when the roentgenogram was taken and the child was struggling Figure 44 A and B

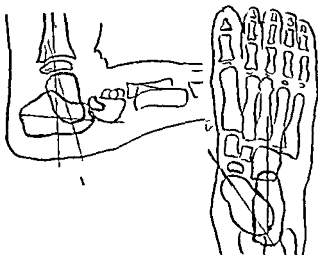
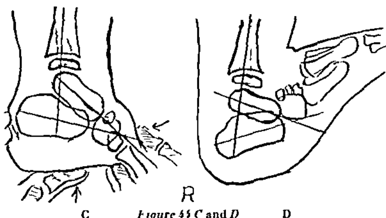


Figure 44 A and B B

In the dorsoplantar view the talocalcaneus angle is 40 degrees There is abduction in Choparts joint with a medial prominens of caput tali The redislocation could easily be reduced without anaesthesia



C *Figure 44 C and D* D

After reduction in plantarflexion it is seen that the talusaxis touches the lower border of the navicular and cuts off the upper 1/3 of the cuboid The navicular in this position is seen to be located anteriorly to the upper ½ of the articular facet of caput tali *e g* in the same position as before the re dislocation (compare Figure 42) It is further seen in Figure 44 C that *in spite of a pronounced plantarflexion in the ankle joint the vertical position of talus has been reduced from 170 degrees to 135 degrees* When correction is made for the plantarflexion in the ankle the real tibio talus angle in this position will be close to normal The talo calcaneus angle is reduced from 80 degrees to normal 35 degrees

Figure 44 D

Rigth foot in maximum dor iflexi n after reduction Both talus and calcaneus are seen to have been flexed in dorsal direction

The talo calcaneus angle has parallell t this enly increased from 30 to 40 degrees

Tibio talus angle R is 105 degrees

Tibio calcaneus angle R 70 degrees (n rmal)

The navi ular lies in a sul luxated position against the dorsal part of the arti cular facet The d rsal pressure exerted against the talus does not longer be so effective that talus is bent int the vertical p sitin een in Figure 44 A

The cause of this is that the d rsal luxati n d es not n w l nger be total It is now a subluxati n an l the pres ure f the foref ot acts now in a blique direction in stead of the in first occurrence rightangled direction relatively to the talusaxis

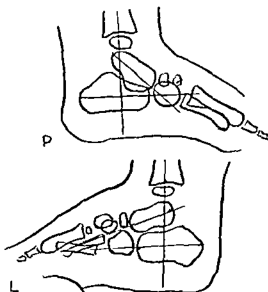


Figure 45

(*Case 16 Cun H* January 29 1964 Age 23 months) *Figure 45*

6 weeks past the acute relaps on right foot was on both feet without weight bearing clinically seen a good longitudinal arch In weightbearing sinks the arch d wn on right foot

X ray both feet in plantarflexion 5 degrees shows on right side some steeping of talus and subluxation of the navicular

Tibio talus angle 135 degrees — degrees (plantarflexion in the ankle) — 10 (value of the maximal dorsiflexion in the ankle) = 120 degrees Proportionally to the verticality of talus is the talo calcaneus angle enlarged to 40 degrees

On left side there is no steeping of talus

(105 degrees — 5 — 10 = 90 degrees) and the talo calcaneus angle is 20 de

grees In accordance with this the talusaxis on right side passes through the lower half of cuboid On left it passes dorsally to the upper border of it but just below the navicular bonecenter New plastercasts were applied for 6 weeks

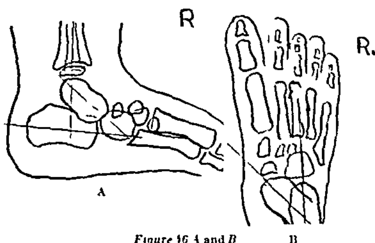


Figure 46 A and *B*

(Case 16 Cun H., April 22 1964 Age 26 months)

She has now been without plastercasts in 6 weeks

X r with the ankle in position 90 degrees Figure 46 A

It is relaps of the subluxation of the right forefoot and on the left too there is a slight degree of subluxation and roentgenological rocckrbottomfoot (See Figure 18 Chapter II page 93)

Tibio talus angle R = 135 — 10 = 125 degrees L = 95 degrees

Talusaxis goes on right foot a great deal plantar to the navicular and passes cuboid below the middle On left it goes plantar to the navicular and goes dorsal to cuboid (See Figure 18 Case 4 Chapter II) X r Figure 45 B Dorsoplantar view right foot shows the talo-calcaneus angle 40 degrees (left 10 degrees) and the talusaxis has a wide medial direction

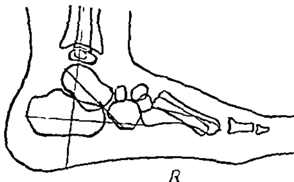


Figure 47

(Case 16 Gun H July 29 1964 Age 28 months) *Figure 47*

She has walked with supports in 5 months Clinically on right foot some medial projection of caput tali (This not on left)

X r in 10 degrees dorsiflexion shows

Tibio talus angle R 135 L 105 (Chapter II left foot Figure 19 page 93)

Tibio-calcaneus angle R 90 L 90

The talusaxis cuts on right foot a lower small part of cuboid and formes a still more steep angle with the calcaneusaxis at the same time as it goes at a great deal of distance plantar to the navicular which have a more dorsal position to the head of talus *I e* the subluxation of the forefoot has progressed (Left foot see Chapter II Figure 19 shows a normal picture)

She uses continuously her supports

(Case 16 Gun H., November 18 1964 Aged 31 months)

Clinically Right foot shows by weightbearing medial convexity and medial projection of the head of talus Left foot shows a quite good longitudinal arch

X ray seen page 95 Figure 21 B Chapter II shows quite unexpected a considerable improvement The talusaxis passes the upper border of cuboid and the lower border of the navicular The talo calcaneus angle has decreased from 45 degrees to 30 The tibio talus angle has decreased from 135 degrees to 100 degrees

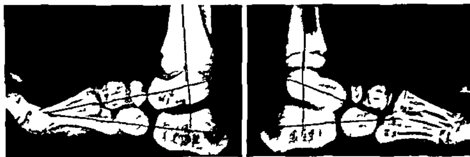


Figure 48

(Case 16 September 29 1965 Age 3 years and 7 months)

Clinically in weightbearing Right foot As before the medial longitudinal arch flattened Leight abduction of the forefoot Left foot The longitudinal arch is here in leight degree at hand From behind is seen some valgus both heels

X ray Figure 48 Both feet maximal dorsiflexion in lateral view The dorsal subluxation which in November 1964 (compare Chapter II page 95 Figure 21 A and B) showed a considerable improvement does not still show relapse but the navicular has to high position The tibio talus angle is 105 degrees—the talo-calcaneus angle in lateral view has decreased to the normal 30 degrees The same with the dorsoplantar talo-calcaneus angle to 35 degrees (see Figure 21 C Chapter II page 96)

X ray Left foot is normal

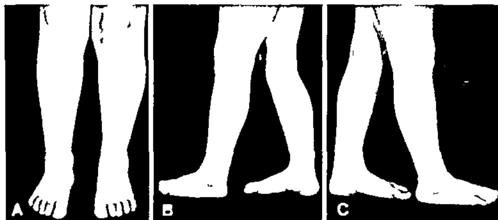


Figure 49

(Case 16 Anne Cun H May 10 1966 Age 4¾ years)

Figure 49 (Case 16 Anne Cun H May 10 1966 age 4¹ years)

Clinically in weightbearing the footarch sinks in some degrees down but the child is during full weightbearing able activity to elevate it The plantar muscles are on *right* foot very well developed—and on direct inspection the footarch therefore looks flatter than it realy is The right foot alltogether looks more powerfull than the left operated foot Left foot shows a rather high footarch and there is in weightbearing only a slight sinking down of it as seen in normal feet In plantar view shows the left foot some excavatus

The axes of the feet looks straight

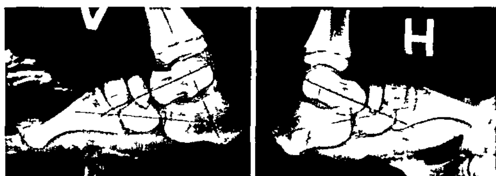
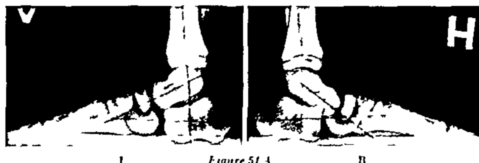


Figure 50

(Case 16 May 10 1966)

X ray both feet in lateral view maximal dorsiflexion Right foot The dorsi flexion is more pronounced than on the picture seven months ago (Figure 48) The tibio talus angle is 95 degrees (left 90 degrees) The tibiocalcanear angle 60 degrees (left 60 degrees)

The tal calcaneus angle has in spite of a smaller til i talus angle increased to 35 degrees due to an increased relative dorsiflexion of the calcaneus This suggests a stronger ligamentar connection between calcaneus and the anterior part of the foot and points to a development towards a normal state The talusaxis touches the plantar edge of the navicular (On the left side it cuts the plantar ¼) I e X ray f the right foot does not show such an ideal condition as n the left f t but there is no real subluxation A picture like this we can se by ordinary children flatfoot (see Chapter I Figure 11 A page 25)



I *Figure 51 A* R

(Case 16 at the same time)

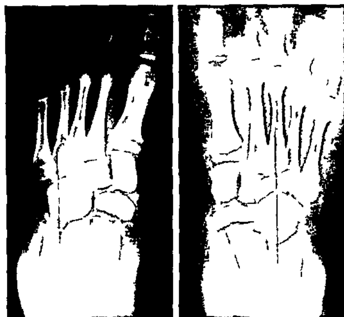
Figure 51 X ray both feet in lateral view *in weightbearing*
Tibio talus angle right foot 115 degrees Left 110 degrees
Tibio calcaneus angle right foot 90 degrees Left 90 degrees
Talo-calcaneus angle right foot 45 degrees Left 30 degrees
The talusaxis right foot passes the plantar edge of naviculare
The talusaxis left foot cuts the plantar ⅓ of naviculare
The talusaxis right foot passes the dorsal ¼ of cuboid
The talusaxis left foot touches the dorsal border of cuboid
I e The position of navicular with and without weightbearing is practically unchanged on both feet

(Case 16 at the same time)

X ray both feet in dorsoplantar view Figure 51 B page 52
Right foot Slight abduction in Choparts joint Talo calcaneus angle 20 degrees Left foot slight degree of adduction of the foot with navicular in supination position and talo calcaneus angle zero

Summary and Discussion of Case 16

Submitted for treatment at the age of 2¾ months Pronounced bilateral congenital convex pes valgus with vertical talus slightly more marked on the left than on the right foot After repeated but unsuccessful attempts to reduce the malformation without operation fol-



L Figure 51 B R

lowed by periods of correction and immobilization in plastercast for a total of 6½ months the right foot rather unexpectedly became reducible and talus stabilized in a normal position (Figure 38–39) The left foot however still withstood all attempts at reduction and had to be operated The right foot was observed without plastercast for 3½ months after which time a plastercast was again applied although the position had remained After another 4 weeks the cast was again omitted but after 6 weeks without the plastercast signs of relapse were present as demonstrated by the talus axis crossing the lower part of the cuboid while on earlier examinations it went close to its superior border Further the tibiotalus angle has increased (Figure 40) To meet this threatening relapse a plastercast was again applied In control examination 3 months later dorsiflexion of the foot was carefully omitted and therefore the roentgenogram was taken in plantarflexion Normal position of the tarsal bones were seen (Figure 42) The navicular ossification center had now become visible After another 4 weeks in plastercast a roentgenogram was taken with the foot in approximately 5 degr dorsiflexion The talus axis now goes just below the navicular which has remained near to its former position at the superior half of the articular facet of the caput tali However it appears to be located slightly more dorsally A dorsoplantar roentgenogram

shows a slight abduction of the forefoot Although the tibiotalus angle in lateral view was 95 degrees one did not feel that the stability of the achieved reduction should be trusted and a new plastercast was again applied to avoid re dislocation The foot was immobilized with the forefoot in marked plantarflexion adduction and pronation On control 4 weeks later the position was to some extent improved The navicular lies at the upper part of the articular facet of caput tali but except for this slight deviation conditions are satisfactorily with normal axes (Figure 43)

Upon changing of the plastercast a weel s later a roentgenogram was not taken but a note was made that there was some abduction of the forefoot on inspection This indicates that the stability at this time was unsafe Moulds were made for supports to be made and the plastercast continued Though the feet upon removal of the plastercasts 7 weeks later clinically lool ed nearly normal *the following radiography showed a dorsal complete reluxation of the forefoot accompanied by a marl ed vertical position of talus* (Figure 44 A B) The clinical picture at the same time was quite changed according to this

The anxious child has been struggling during the X ray examination —and the explanation of the acute relapse is that this struggling has brought about a too vigorous passive dorsiflexion by keeping the foot in site during the X ray procedure when no doctors were present However the dislocation could now easily be reduced without anaesthesia contrary to the situation before the first reduction succeeded one year ago (Figure 44 C) After the reduction an erection of talus was observed

An attempt of dorsiflexion was cautiously made too the try the stability The complete dislocation did then not occur—only a subluxation and some steeping of talus occured parallell to this (Figure 44 D) The condition of the right foot should be considered satisfactorily from the time full reduction was supposed to have succeeded Nevertheless the navicular remained in its somewhat dorsal position in front of the upper part of the articular facet of caput tali but this may also be seen in normal feet (see Case 6) and the navicular in Case 16 remained above the talus axis even after what appeared to be a complete correction of the redislocation achieved by maximal plantarflexion of the forefoot (see Figure 44 C) As the patient came for treatment relatively late and reduction did not succeed until 6½ months later the position of the forefoot achieved at the correction must have been very unstable due to the before mentioned changes

that occur of the caput tali. Therefore passive dorsiflexion past 90 degr. should not have been exerted on control examinations at that time. By the dorsal luxation of the forefoot talus had been forced into the vertical position at the moment of dislocation, its distal part being pressed from above.

As pointed out above, this is a demonstration of how the primary congenital dorsal subluxation or luxation in Chopart's joint produces a secondary vertical talus. *This implicates certain therapeutic consequences.*

The further development of the right foot after the total reluxation shows that a safe position was not achieved for a long time.

By using supports a good improvement was certainly obtained, but the navicular always remained positioned a little too high (Figure 45, 46, 47, Chapter I, Figure 21B, page 95, Chapter II). This was also seen during the first time after operation at the operated left foot (Figure 18, Chapter II). But on this side an improvement to a normal foot took place quite quickly, while on the right side treated with closed reduction a tendency to relapse persisted until the child was about 3 years.—Then a tardy improvement occured.

No other treatment than supports was used. After 4 years the improvement to an ordinary reducible flatfoot of common type is incontestable. She is able to elevate the footarch actively in full extension (Figure 49 B, C).

And X-ray in full weightbearing shows no dorsal subluxation of the navicular, although it is not so accurately centered to the articular facet of the head of talus as on the operated left foot.

The somewhat steep position of talus in weightbearing (Figure 51) is not more than seen by ordinary soft childrenflatfoot (compare Figure 11 A). The continuous treatment is supports or orthopedic shoes and full recovery to a quite normal foot is to be expected in the future.

VI Comparison Between the Roentgenogram in Congenital Convex Pes Valgus with Vertical Talu and the Rockerbottomfoot Deformity Seen as Complication in Cases of Talipes Equinovarus Congenita which are under Treatment

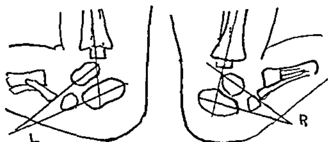


Figure 52

(Case 19 Morten H 7 weeks old)

Treated for bilateral clubfoot Bilateral rockerbottomfeet have occurred during this treatment

Roentgenogram in maximum dorsiflexion Lateral view

Tibio talus angle R 105 degrees L 110 degrees

Tibio-calcaneus angle R 90 degrees L 110 degrees

Talo calcaneus angle R 20 degrees L 10 degrees

The talusaxis on the right passes the upper border of cuboid on the left it passes considerably more dorsally to the bone

The calcaneus axis touches the lower border of cuboid on both feet

The size of the tibio talus angle and the tibio-calcaneus angle differentiates not mutually very much as the equinus position of calcaneus expressed through the tibio calcaneus angles here is relatively wide In consequence of the small difference between the two mentioned angles the talo calcaneus angles will be small

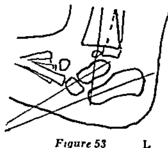


Figure 53 L

(Case 20 Hilde H 18 weeks old)

Left sided clubfoot with secondary rockerbottomfoot

Roentgenogram of left foot in forced dorsiflexion

Tibio talus angle I 120 degrees
Tibio calcaneus angle I 110 degrees
Talo calcaneus angle I. 5 degrees
The talusaxis cuts off the upper ¼ of cuboid The calcaneus axis goes considerably below it

I e like in preceding case we here see a very small difference mutually in the size of the tibio talus to the tibio calcaneus angle and the talo calcaneus angle is consequently very small The passing of the talusaxis proportinally in the upper part of cuboid contradicts a dorsal subluxation in Chopart s joint

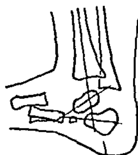


Figure 54

(Case 21 Jon J aged 6 weeks)

Clubfoot successfully treated without the occurrence of a rockerbottom deformity Roentgenogram in dorsiflexion
Tibio talus angle 115 degrees
Tibio calcaneus angle 85 degrees
The talusaxis and the calcaneus axis cross at a 45 degrees angle The talusaxis passes dorsally to cuboid the calcaneus axis goes through the upper border of cuboid

Summary and Discussion

The here demonstrated three cases of rockerbottomfoot occuring during treatment for congenital talipes equinovarus have the following peculiarities in common The equinus of talus is relatively small as compared to that of calcaneus Further the equinus of calcaneus is bigger than the one commonly observed in congenital convex pes valgus with vertical talus The consequence of the mentioned facts is that the talo calcaneus angle is small or even non existing

In congenital vertical talus and in cases of successfully treated club foot (see Figure 54) like normal feet there is a marked convergence between the talus and calcaneus axes which cross each other at angles of 25–40 degrees or more Correspondingly the articular space is supposed to become narrower anteriorly It is further seen that the

talusaxis by the rockerbottomfoot by clubfoot in spite of the steeping of talus constantly passes dorsally to or through the superior part of the cuboid in contrast with the finding in congenital convex pes valgus with vertical talus The cause of this may be that by the secondary rockerbottomfoot in pes equinovarus generally no or only a slight dorsal subluxation in Chopart s joint is present whereas this in cong convex pes valgus w vertical talus is the most important appearance

Survey of the Material of Chapter I and Discussion

A favourable result by conservative treatment in congenital convex pes valgus with vertical talus depends on an early diagnosis and an early start of the treatment

When on clinical examination a congenital rockerbottomfoot is seen the disorder may be suspected but the diagnosis of a vertical talus can only be settled through roentgenological examination

During the first days after birth the roentgenogram often shows only the ossification centres of talus and calcaneus which in addition may display irregular forms at this early stage Therefore the roentgenological diagnosis at this time may often be rather difficult In order to arrive at the correct diagnosis it was deemed necessary for the sake of comparison to establish the pattern in normal feet as well as in conditions which clinically may resemble the picture of vertical talus

The investigation has shown that the time for the roentgenological appearance of the ossification centres of the tarsal bones vary considerably (*Kohler* 1953) In the present material the centre of the cuboid became visible on the roentgenogram from the 3rd–4th day and up to the 20 th day after birth The cuneiformI–II and III become visible later than the cuboid but considerably earlier than the navicular and therefore may be misinterpreted as being the navicular by an unexperienced examiner

The navicular centre appears from 1½–4 years of age and its lower ⅓–¾ or more is often covered by the cuboidal ossification centre A homogenous rightsetting in making the X ray photographs is obviously difficult to obtain and this must of course be taken into consideration by judgement of the pictures

In order to decide the vertical position of talus in the anklejoint and mutual position of caput tali and the navicular before the appearance of the actual ossification centres the earlier mentioned axes and angles have been applied

To establish a comparable and constant basis for comparison of the vertical position of the talus in the different cases all feet have been photographed in the lateral view in maximal dorsiflexion, except in a few cases where certain circumstances prevented this The tibiotalus angle in the present material of normals varied from 50 degr (Figure 1) —105 degrees (Figure 5) The tibio calcaneus angle normally varied from 10–75 degrees This maximal value is probably too low but valeus above 85 degrees consistently seem to indicate equinus position of calcaneus presupposed that the foot has been X rayed in maximal dorsiflexion (See earlier notes about the evaluation of the parameters) The posteriorly open angle between the axes of talus and calcaneus (the talocalcaneus angle) was normally found to be in average 25–35 and always less than 55 degrees In cases of congenital convex pes valgus with vertical talus this angle generally is wider than normal and may reach values of 80–90 degrees (Figure 22 and Figure 44 A) In simultaneous equinus of the calcaneus the angle will be decreased and obviously more the higher the degree of equinus of calcaneus and the less the verticality of talus But even in cases with relatively moderate vertical position of the talus and equinus of calcaneus the angle in the present material by v talus wes never observed to be less than 40 degrees (as compared to the observed limit of 50 degrees in normal feet) (Figure 7 R shows 55 degrees but is an exception see page 20) Case 16 page 59 Figure 48 right foot shows the talocalcaneus angle diminished from 70 degrees to 30 degrees after conservative treatment and the left to 25 degrees after operative treatment About the enlarging of the talocalcaneus angle by increased dorsiflexion of calcaneus but without changing in the position of talus following lengthening of the Achillestendon and other causes of reduction of the achillesfunction see page 14 Remarks about the talocalcan angle and page 47 Some reflexions about lengthening of the achillestendon In cases rocker bottomfoot seen during treatment for congenital clubfoot the talocalc angle was only a few degrees or non existing (Figure 52 and Figure 53) The equinus position of calcaneus in these cases was rather dominant in relation to the vertical (or equinus) position of the talus For the evaluation of the position of the imaginary bone center of the navicular and thereby diagnosing a dorsal subluxation in Choparts joint an examination was made of the mutual relationship between the longitudinal axis of the talus and the ossification centre of cuboid In maximal dorsiflexion the talus axis normally cuts through the middle of cuboid or through the upper half of the bone (Figure 3 L) or passes

the bone dorsally (Figure 3 R) In early childhood and by hypermobile flatfeet by children when on X ray a vigorous pressure is exerted under the forefoot the resulting talus axis may cut through the lower half of cuboid (Figure 5) and even touch the lower border of the bone (Figure 8 left) or pass just below it (Figure 4 left foot) This is due to a yielding of the hypotonic ligaments resulting in a dorsal movement in Chopart s joint but without any real subluxation When examined four years later in a equal situation the talus axis was found to touch the *upper* border of cuboid The former hypotonicity of the ligaments which permitted the abnormal dorsal move ment in Chopart s joint was assumed to have disappeared spontaneously at this time leading to the observed change in the course of the talus axis proportionally to cuboid Concerning the talusaxis the same find ings as in normals are seen in cases with benign pes calcaneus in the new born (Figure 7 L and 8) in congenital pes calcaneovalgus (Figure 9 A 9 B and 9 C) and in pes planus in children (Figure 10 A 11 A B)

In the presence of vertical talus the long axis of the talus will pass below and behind cuboid (Figure 12 right Figure 13 right Figure 22 right foot and Figure 36 both feet) and may cut through the anterior part of calcaneus or pass the bone anteriorly rather close to its anterior border (Figure 22 Figure 36 and Figure 13 right foot) During treat ment when the dorsal subluxation of the forefoot in Chopart s joint and the vertical position of talus are being gradually reduced one can observe how the talus axis gradually changes its course and cuts through the cuboid more and more dorsally (right foot on Figure 13 14 16 and 17) However *one must keep in mind that the vertical course of the talus axis does not alone decide its relation to the cuboid* but the extent of the subluxation of the forefoot has a considerable influence on this relation As it is evident from Case 2 Figure 8 B page 83 a considerable luxation of the forefoot is by particular circumstances followed by only a small steeping of the talus In this event the talus axis is passing below cuboid independent of the small extent of the steeping As before maintained the greatest difficulty that may be encountered in attempting to diagnose a vertical talus immediately after birth is the triangular or even circular shape of talus sometimes seen at his early age making the drawing of the longitudinal axis questionable (Figure 1 R) An elipsoid form of the ossification centre makes the drawing of the axis much easier (Figure 18 L) In all cases treatment with reduction of the rocekrbottomfoot and with corrective plastercast may be started at once as if a vertical talus had been diag

nosed and in a short time when the ossification centre of talus had achieved a shape that permits the drawing of a more unquestionable axis the diagnosis can be reviewed More doubtful cases should not however be *listed* as congenital convex pes valgus with vertical talus because this will lead to a better prognosis for conservative treatment than deserved

Also calcaneus may during the first days after birth present a radiological shape that makes the drawing of the longitudinal axis difficult (Figure 18 I) In the present study the observations made at later ages seemed to prove that the axis drawn at the early examinations were correct

Pronounced congenital pes calcaneo-valgus with contractures which clinically presented a rockerbottomfoot but *radiologically without vertical talus or subluxation,* was demonstrated in an otherwise healthy girl aged 10 months (Case 9) The contractures in this case (of tibialis anterius the long toe extensors and the peronei) were so firm that they could only be corrected by using a considerable force under general anaesthesia and after two reductions Figure 9 A demonstrates that the skeleton of the foot is normal Observation at the age of 9 years shows a normal development of the foot Congenital convex pes valgus with vertical talus is most often accompanied by pes abductus with a medially prominating caput tali (Chapter I Figure 22 B) The dorsoplantar roentgenogram however demonstrates a *reducion* of the talo calcaneus angle contrary to what is found in the ordinary pes plano valgus The reason for this is that a concommittant adduction of calcaneus is present in a great part of cases with congenital dorsal subluxation in Chopart s joint that more than outweighs the increase of the dorsoplantar talo-calcaneus angle caused by the medial deviation of the talus axis and thus leading to a resulting decrease of this angle As demonstrated in Case 15 this reduction of the talo calcaneus angle is accentuated after correction has been performed when the angle may be reduced to 5–10 degrees or even to zero the axes running a parallell course (Case 15 Figure 28 A B) Essentially there is an anatomical difference between the abduction seen in cases with congenital vertical talus and those in ordinary pes planovalgus In the first case the abduction mainly or entirely takes place in Chopart s joint In the second case the abduction is part of an ordinary pronation movement Calcaneus connected with the forefoot makes an abduction in relation to the talus which is fixed in the ankle joint As known thereby the angle between calcaneus and talus (in the dorsoplantar view) is

increased In some cases of vertical talus however there is no adduction of calcaneus and then the dorsoplantar talocalcaneus angle is wider Chapter II Case 1 Figure 3 B Case 7 Figure 8 C left page 83)

Treatment

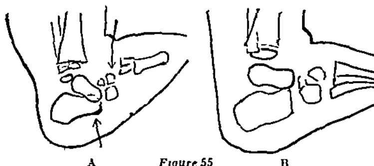
A distinction is made between the cases that permit non operative (closed) reduction and those where an operation is needed to achieve reduction (open red) The age of the patient is decisive as to whether the disorder will need operative treatment or not In the present material non operative reduction was possible in all cases where *purposeful* treatment was started during the first days after birth That this may not always be the case was clearly demonstrated by Günz (1939) who reported the post mortem findings in a new born of rigid contractures that could only be lessed through extended tenotomies and cutting of ligaments (see page 11) In addition to the cases treated of an early age non operative reduction was achieved in one patient where treatment was started at an age of 2½ month but the reduction did not succeed before the age of 9½ month (Case 16 Figure 36 B) This case was the only one where closed reduction at such a high age succeeded but at the same time it displayed a more marked tendency to resubluxation compared to the operatively reduced foot The explanation for this is the persisting pull of the not intersected ligaments

It looks however as if the tendency to re subluxation successively is decreasing when the child is using suports preferably combined with increased height of the heels of the shoes Figure 57 It is then provided that a real reduction has originally been performed Elimination of the resistance brought about by the contracted ligaments is the key to a successful reduction both in non operative and operative treatment The teno muscular resistance may relatively easily be overcome

The ligaments mainly involved (see Chapter II Figure 1 and 2) are lig talo naviculare dorsale and lig tibio naviculare which at operation are found to be hypertrophied preventing reduction of the dorsal component of the dislocation Further the lig talo-calcaneare interosseum which resists reduction of the laterally dislocated calcaneus And finally the lig calcaneocuboideum tends to prevent reduction of the abduction of the forefoot seen in Chopart s joint (Figure 1 a b section II page 76)

Successful closed reduction is achieved through stretching of these ligaments By operative reduction the ligaments are incised to the needed extent

Reductionmanoeuvres by Closed Reduction



A *Figure 55* B

The reduction manoeuvres are performed by exerting a downwards pressure upon the dorsally dislocated forefoot which may be felt as a prominence just in front of the anterior curve of the ankle Simultaneously a counter pressure is exerted upon *the plantar and anterior aspect of calcaneus in a dorsal direction Figure 55 A* The forefoot is then forced into a maximal plantarflexion and also adducted and pronated

A *Figure 56 A* and *B* B

If the dorso plantar roentgenogram demonstrates a small talo calcaneus angle (*e g* adduction of calcaneus) both the forefoot and the processus posterior calcanei are forced in a medial direction (Figure 56 A) (eventually by using a Lorenz ingot)

If the dorso plantar talo-calcaneus angle is wide(*e g)* abduction of calcaneus wit median position of processus posterior of calcaneus) this must be forced in lateral direction but still the forefoot is to be pressed in a medial direction (E The foot is immobilized in the plastercast with the forefoot in maximal adductio plantarflexion and pronation and is molded into a well defined plantar concavit *carefully avoiding* an *upward pressure anteriorly* to the corpus calcanei which migh lead to redislocation

The second important point in the treatment is maintenance of the achieve position after reduction Also concerning this part of the treatment the earl treated cases have proved more favourable This is in keeping with what has bee reported earlier about the changes which gradually occur in the articular surface Of special importance is the dorsal recession of the caput tali which is caused b the pressure of the dorsally dislocated os naviculare

This dorsal flattenedgeing of the head of talus will after reduction offer poo support to the navicular which is readily re dislocated dorsally This difficulty i met in both closed reduction (Case 16 Figure 47) and operative reduction (Figur 9 L Chapter II page 85)

As emphasized (page 85) must no vigorous dorsiflexion of the forefoot be mad and a dorsiflexion should not at all be done during the controle X ray by th changing of plastercasts and not before a long time after the cast has been omitte

This rule is formed on the basis of experiences made in the most pronounce cases(Case 15 and 16) conservative treated in this material It is plausible in Cas 15 and 16 to assume that the recovery by the primary well succeeded close reduction on right foot has been lengthened by a later insufficiently systematica accomplished treatment Evidently milder cases as 12 13 14 show that an appa rently insufficient treatment in early age can give good results—and it may b permitted to try a shorter but exacctly controlled treatment in equal cases Case 1 demonstrates how total relapse occurred upon uncontrolled forced dorsiflexio during X ray examination In the same illustration it is shown how the forefoot a

(please turn over



Figure 57

The Figure 57 shows the principle of the high heeled shoe in aftertreatment o reducted congenital convex pes valgus W vertical talus The heel part of the sol hall have an *anteriorly* upward direction with its main supports under the *anterio* part of calcaneus *but posteriorly* to the forefoot The fateful unrolling of the fore foot from the ground is considerably reduced by this shoe

the occurrence of re dislocation forces talus into a vertical position Since the steeping of talus is considered to be secondary the transposition of muscles and ligaments in order to keep it erected may not be indicated This material as well the conservative treated as the operative proves this

The same material contradicts the necessesity of lengthening of the achilles tendon in the most cases

CHAPTER II

The Operative Reduction of Congenital Convex Pes Valgus with Vertical Talus

The purpose on the operative reduction is in operative way to eliminate the tension of ligaments and tendons which prevents reduction and than do the reduction under direct vision

In the present cases full reduction has been achieved after a planned cutting of the ligaments Lengthening of tendons or operations upon the osseous tissue have not been necessary To obtain full reduction the navicular must be brought into correct position to the articular facet of the head of talus

Operative reduction has been used when closed reduction has failed The age of the patients has varied from 9 months to five years Operative *reduction* should be distinguished from operations which are performed to *prevent recurrencies* However at the time of open reduction stabilizing corrections as well may conveniently be done and may be considered an advantage of using the operative treatment Further in cases where primary conservative reduction succeeded but a tendency to recurrence persisted good results may be achieved only by discision of mainly the tibio navicular ligament which is believed to promote recurrence by maintaining a constant pull of the reducted forefoot in an unfavourable direction

Operative Technique

The protruding dorsolateral part of the forefoot is exposed through a lateral longitudinal incision The protrusion indicates the site of the dislocated os naviculare The tendons of the muscles extensor digitorum longus are retracted mainly The short muscles of the dorsum pedis are detached at their origin The lateral part of ligamentum talo naviculare dorsale is now exposed The ligament is often found to be hypertrophic forming a bridge between the dislocated os naviculare and talus Connected with this ligament is the less distinct ligamentum

the occurrence of re dislocation forces talus into a vertical position Since the steeping of talus is considered to be secondary the transposition of muscles and ligaments in order to keep it erected may not be indicated This material as well the conservative treated as the operative proves this

The same material contradicts the necessesity of lengthening of the achilles tendon in the most cases

plantar flexion of the foot pulls os naviculare dorsally as related to caput tali (Figure 1 B) thereby forming a major obstacle to successful reduction This ligament is part of the anterior part of the deltoid ligament A less distinct part of he deltoid ligament is located further anteriorly and is bridged between tibia and collum tali Tenotomy is *only* performed of the tibio navicular ligament *and neither of the tibio talar* nor the posterior tibio-calcanear parts of the deltoid ligament

Apart from the above mentioned ligaments ligamentum talo cal caneum interosseum may also prevent successful reduction mainly by preventing reduction of the laterally sub luxated os calcaneum (Case 1) Theoretically ligamentum calcaneo-cuboideum might counteract re duction of the abnormal abduction in Choparts joint (Figure 1 A) but in my cases no tenotomy of this ligament has been necessary

After tenotomy of the named ligaments reduction could be accom plished by digital pressure upon the dorsal facet of os naviculare and simultaneous plantar flexion and adduction of the forefoot which is also at the same time pronated A dorsal traction upon caput and col lum tali with a bonebook will help the reduction manoeuvre but must de done very cafully because—as happened in one case (Case 3 page 85)—the epiphysis of caput tali may be damaged and even torn loose When os naviculare has been brought into a correct position to caput tali correction of the vertical position of talus will spontaneously follow especially in the presence of a slight overcorrection which makes the navicular exerts a press upon the head of talus in a slightly dorsal direction Figure 8 D page 84 The reduction manoeuvre may result in excavation of the planta pedis and adduction of the forefoot as well as a slight varus of os calcaneum—*i e* the picture of a pes excavatus aaductovarus (Figure 5 page 81)

On attempt at omitting this overcorrection a tendency to re-dis location usually will occur The difficulty of maintaining normal re-duction without introducing overcorrection is caused by the dorsal flattening of the caput tali thus giving poor support to the reduced os naviculare Some means of fixation of os naviculare to caput tali may be necessary in a number of cases in order to maintain reduction This fixation may be done by a Kirschner wire (Case 4) or better with expediently placed silk sutures

In one case (Case 1) a silk suture was placed between caput tali and the upper part of the lateral malleolus in order to keep the talus in a horizontal position and herethough prevent a gliding of naviculare dorsally After the operation immobilization in plastercast is used for

12–14 weeks Then supports are accurately molded However better than supports are the high heeled shoes or boots (Chapter I Figure 57) Operative lengthening of the achilles tendon has not proved necessary—not even in the cases when such lengthening upon pre-operative examination was deemed unavoidable (Case 1 Chapter II page 80 Chapter I page 47) In one bilateral case lengthening of the achilles tendon was done primarily because the tendon appeared to be considerably contracted However the procedure had no definite influence upon the vertical position of talus nor did it facilitate closed reduction (Figure 13) which primary was attempted (Case 3 Chapter II page 85)

Case Report

Case 1 John A Male Born November 2 1951

The patient was first seen on January 28 1953 at the age of 15 months He had started to walk at the age of 12 months

Status January 28 1953 Bilateral irreducible rockerbottomfoot severe degree Passive dorsiflexion took place in Choparts joint without attending movement of the heel



Figure 2 A Case I Left foot in passive dorsiflexion before the operation and one year after See text



Figure 2 B Left foot in weightbearing before the operation and one year after See text

Figure 2 A demonstrates the *abnormal* dorsiflexion in Chopart joint before operation and the *normal* conditions one year after Figure 2 B demonstrates full weightbearing before the operation and after The right foot not illustrated shows the same condition

Radiographs of both feet (lateral views) before operation The dorsal dislocation in Choparts joint of the forefoot and the vertical position of talus are demonstrated Tibio talus angle 175 degrees Due to the equinus position of calcaneus most marked on the right foot the tibio calcaneus angle is wide—105 degrees while the talo calcaneus angle is relatively small—40 degrees in spite of the pronounced vertical position of talus (See Chapter I page 14 and 47)

The dorso plantar talo calcaneus angles are large—L 55 degrees and R 45 degrees Figure 3 B

May 11 1953 Under general anesthesia and bloodless field operative reduction was performed on the *left* foot (the child was now 17 months old) Lateral longitudinal incision Reduction was achieved after cutting of the named ligaments (Figure 1 A and B)

A tight ligament of silk was applied between the lateral malleolus and collum tali to keep talus in dorsiflexion (At the time of operation a later operative



Figure 3 A

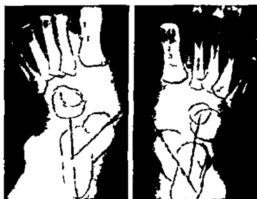


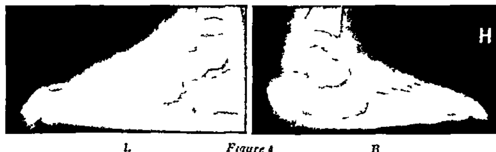
Figure 3 B

lengthening of the achilles tendon was planned which later proved unnecessary look page 47 Chapter I) The plastercast which was applied at the end of the operation was removed after 12 weeks X ray then in lateral view demonstrated normal position of the bones of the forefoot In the dorso plantar view the talo calcaneus angle had been reduced from 55 degrees to 10 degrees

On July 3 1953 the child now being 18 months old operative reduction was done on the *right* foot Longitudinal incision In addition to the dorsal dislocation in Choparts joint the calcaneus here was found to be sub luxated laterally to a higher degree than usual The operation was done as described above The position was here maintained by plastercast, alone with the forefoot in pronounced plantar flexion and adduction The plastercast was removed after 12 weeks

Figure 4 X ray in lateral view shows the left foot 6 months after the operation and the right foot 5 months after operation The tarsals bones show normal position However in the dorso plantar view the talo-calcaneus angle was 0 degree on the left foot and 10 degrees on the right The clinical result is hown in Figure 2 A B Inspection of the planta pedis revealed a slight pes adductus of the left foot This became more pronounced by the time and two years after the operation con servative reduction was attempted with following immobilization in plastercast for 8 weeks but with no success

February 19 1958 5 years after operation the leftsided pes adductovarus was still present The right foot had remained normal (Figure 5)



L *Figure 4* R



Figure 5 Case I Five years after the operation Left sided pes adductovarus

July 3 1958 operative reduction was done of the leftsided pes adductovarus through a medial longitudinal incision At the operation os naviculare was found *in a supinated position its articular surface prominating 1 5 millimeter medially* to the articular surface of caput tali Full reduction was not achieved and therefore the incised medial ligaments between os naviculare and caput tali were not re sutured The operation now was followed by 3 weeks in plastercast the last five with a walking cast Later a night splint was used October 13 1961 three years after the last operation the feet both appeared normal except for the tendency of the first toes towards hammertoe position as in a case of ordinary pes excavatus

June 20 1963 ten years after the first operation (Figure 6) The boy now 11 5 years old took part in different sport activities without being hampered by his feet

Status He walks normally The foot arches are excavated No valgus or varus The hammertoe position of the first toes have increased—mainly on the left foot



Figure 6 Clinical appearances 10 years after the operation The arch of the foot is excavated but without causing any complaint Keen on sport



Figure 7 Case I 10½ years after the operative reduction X ray both feet in maximal dorsiflexion See text

X rays lateral view of the right foot shows no steeping of talus (tibio talus angle = 95 degrees) Os naviculare is subluxated slightly dorsally to the articular surface of caput tali (the axis through talus touches just navicular plantarly) The navicular is wedge shaped towards planta pedis The corners of caput tali are pointed The medial arch of the foot is excavated. X ray of the left foot shows no dorsal subluxation of the navicular The talusaxis passes through the lower edge of the navicular No vertical position of talus (tibio talus angle 90 degrees) The navicular shows a slight wedging The pointed angles of caput tali are pronounced The excavation of the arch is less than on the right side

Case 2 Vivian St J Female Born August 10 1955

The patient was first een at the age of three years She had a leftsided rocker bottomfoot with marked pes valgus and vertical talus The right foot was normal At the time of the first examination (June 11 1958) she was under treatment for hypothyroidism

Roentgenogram of the left foot in 5 degrees dorsiflexion lateral view The navicular ossification center is not visible in spite of her age (Hypothyroidism) Tibio talus angle 125 degrees Tibio-calcaneus angle 90 degrees The talusaxis goes

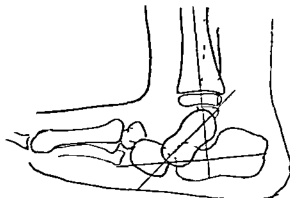


Figure 8 A

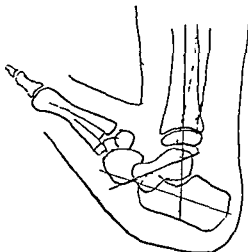


Figure 8 B

through the lower ¹ of cuboid the calcaneus axis through the lower 1/3 The pronounced rockerbottomfoot which is present in spite of a relatively small deviation from the normal course of both these axes is due to the considerable dorsal dislocation seen in Choparts joint

Figure 8 B The same foot in *maximum* dorsiflexion Tibio talus angle has been *reduced* to 105 degrees the tibio-calcaneus angle to 75 degrees It may be concluded that a dorsally dislocated forefoot not always will force the talus into a vertical position The vertical position of talus is produced by the pull exerted upon the

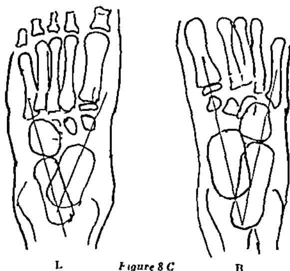


Figure 8 C



Figure 8 D Case 2 X ray during operative reduction The reduced forefoot pushes talus up to a horizontale position The undesired excavatus position is seen to occur

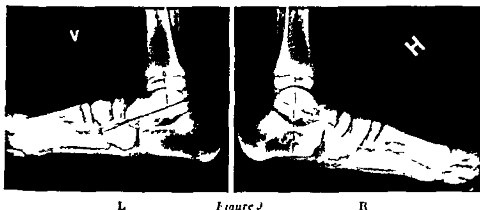
dorsally dislocated forefoot by the plantar foot muscles However marked hypotonicity of the muscles was seen in this case (due to her hypothyroidism) and may possibly be the cause why talus here not was forced down in a more vertical position in spite of the marked dorsal dislocation of the forefoot

Dorsoplantar talo-calcaneus angle left side wide 40 degrees Right 30 degrees The general condition of the patient did not at this time permit operative intervention

Two years later on May 2 1960 she was then 5 years old operative reduction of the dislocated left Choparts joint was done as described above It was noted at the operation that the head of talus showed a considerable dorso lateral flattening caused by the pressure exerted by the dislocated os naviculare In this case too a tendency to overcorrection with resulting pes excavatus was seen during reduction

Figure 8 D demonstrates this situation The overcorrection was reduced but no internal fixation of the achieved position was instituted only a plaster cast X ray taken after 7 weeks when the cast was removed showed a moderate relapse with subluxation and slight vertical position of the talus However the dorsoplantar talo-calcaneus angle which before operation was 40 degrees was now 20 degrees

October 20 1960 three months later re operation was done This time the skin was incised anteriorly to the *medial* malleolus and forward along the medial side of the foot *The tibio naviculare ligament appeared intact as did the medial part of the dorsal talo navicular ligament When these ligaments were incised reduction could easily be accomplished with no tendency to overcorrection or pes excavatus* This time to prevent re dislocation in Choparts joint two silk sutures were placed medially between os naviculare and os calcaneum The operation was followed by immobilization in plastercast for 8 weeks and then supports were used X ray control December 14 1960 still showed some subluxation



L *Figure 9* R

June 21 1963 two years and nine months after the last operation the girl was now 8 years old Roentgenogram now shows only a very slight degree of subluxation (Figure 9 L) The talusaxis touches the lower border of os naviculare (on the right foot which is an ordinary flatfoot the axis goes through the lower 1/3 Figure 9 R *The flattening of the dorsal aspect of the articular facet of caput tali which was seen at operation is clearly demonstrated on the roentgen gram*

(Compare Chapter I) No vertical position was seen of the talus (tibio-talus angle 95 degrees) Clinically a slight pes plano valgus was seen but less than on the "normal" right foot (Figure 10)



Figure 10 Case 2 Age 8 years clinical appearance in full weightbearing Three years after operative reduction a small degree of ordinary flatfoot but less on the operated original congenital convex valgus with vertical talus

Case Tormod H Male born January 20 1960

The patient came to examination two days after birth Marked bilateral rocker bottomfoot was found (Figure 11) with pes valgus and abduction contracture most marked on the left side Apparently the malformation of the feet had been successfully corrected at first attempt without anaesthesia and no roentgenogram was made



Figure 11

On clinical examination 14 days later (also without a roentgenogram) the rockerbottomfoot still seemed to have been successfully corrected although some abduction of the forefoot persisted After another 4 weeks in correcting plastercast the feet looked normal and the casts were omitted 14 days later control examination revealed a complete relapse Two periods now followed with reductions and plaster casts but relapses occured whenever these were removed

September 7 1960—the child was now 8 months old—*the first roentgenogram was made* and the diagnosis of bilateral vertical talus was established At this time the feet appeared clinically rather nice except for a significant contracture of the achilles tendons with a marked wrinkle across both heels

Figure 12 A Roentgenogram in lateral view of both feet in maximal obtainable dorsiflexion (dorsiflexion of right foot 20 degrees left 5 degrees)

Tibio talus angle R 160 degrees L 175 degrees—note the wider tibio talus angle on the left side in spite of the clinically less passive dorsiflexion The reason for this is as seen of the X ray—that the dorsal movement takes place in the Choparts joint not in the anklejoint and that the dorsally on this side completely dislocated forefoot obviously pushes the talus in an increased steeping

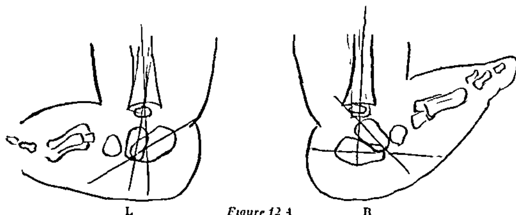


Figure 12 A

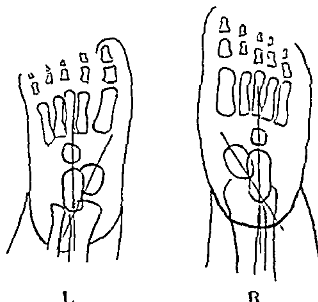


Figure 12 B

Tibio-calcaneus angle R 90 degrees L 115 degrees
Talo-calcaneus angle R 45 degrees L 40 degrees
There was marked equinus position of the left calcaneus

Figure 12 B Roentgenogram of both feet in dorsoplantar view The talo calcaneus angle is seen to be narrow (compare Chapter I Case 15 Figure 28 page 40)

Because of the contracted achilles tendons a primary lengthening was performed on both feet on March 7 1962

Roentgenograms had been made four months before the lengthening of the achilles tendons after attempted reduction under anaesthesia as well as shortly after the operation The pictures were equivocal

Obviously no improvement had achieved on the left foot while on the right some slight improvement towards reduction had occured However the pictures may have been made in unequal manual pressure in dorsiflexion and therefore permit no conclusion The pictures for this reason are omitted here

July 4 1962 The patient now aged 2¼ years was again seen In the meantime he had been using supports Pes calcaneus and a severe degree of pes plano valgus with rockerbottomfoot was found bilateral but most pronounced on the left

Figure 13 Roentgenogram of both feet lateral view in maximal dorsiflexion

Tibio talus angle R 100 degrees L 130 degrees
Tibio-calcaneus angle R 70 degrees L 80 degrees
Talo-calcaneus angle R 35 degrees L 55 degrees

Similar to the findings in Case 2 a distinct rockerbottomfoot with dorsal dis location in Choparts joint is present on the right side although talus does not take

ACKNOWLEDGEMENTS

I should like to express my gratitude to my friend and former teacher Professor C. GÖSTA JANSSON, M.D., who directed my interest to the radiology of skeletal diseases.

The present study was started in 1955. At this time a relatively large number of patients with coxa plana had been registered at the Radiological Department of the Orthopaedic Hospital of the Invalid Foundation, and some primary results of healing could be evaluated. I am deeply grateful to the late Professor FABIAN LANGENSKIÖLD, M.D., the former Head of the Hospital, for his initiative and valuable guidance in the early stage of the work.

Since the autumn of 1956 my work has been followed with interest and encouragement by my present chief Professor ANDERS LANGENSKIÖLD, M.D. In the evaluation of the various aspects of the radiological course in coxa plana I have thus had the advantage of profiting by Professor Langenskiöld's extensive knowledge on the normal and pathological mechanisms of bone growth. He also revised my manuscript with constructive criticism. For all this generous aid I wish to extend my warm thanks.

My thanks are due to my colleagues at the Orthopaedic Hospital of the Invalid Foundation, who helped me with the radiological examinations and examined the patients clinically.

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Helsinki, March 1965 WALTER EDGREN

I INTRODUCTION

Among the so called aseptic necroses coxa plana occupies a central position owing to the relatively frequent occurrence of the disease and owing to the fact that its location to the hip joint which is of such great significance to the mobility of human beings makes it a serious clinical and social problem

The denomination coxa plana introduced by H WALDENSTRÖM in 1920 describes the deformity — a flattening of the femoral head — caused by the disease

In the extensive literature concerning the radiological course in coxa plana interest has mainly been focussed on the changes of the femoral epiphysis and the ultimate shape of the latter after the completion of healing In spite of the great importance of the metaphysis and the greater trochanter for the modelling of the proximal end of the femur and although the trochanter in addition influences the statics of the hip joint less attention has been directed to the changes in these structures

On inspection of serial radiographs of patients with coxa plana I observed that end results which were satisfactory from the standpoint of the shape of the femoral head were sometimes markedly impaired because the greater trochanter was abnormally large in relation to the head and neck of the femur In certain cases the tip of the trochanter extended by several millimetres over the proximal surface of the femoral head

It seemed a reasonable assumption that this secondary deformity was due to premature closure of the subcapital growth line of the affected hip as compared with the subtrochanteric growth line in which growth sometimes continued for a long time after the vertical growth of the metaphysis had been arrested

Furthermore I observed that certain changes of the metaphysis almost constantly occurred on the radiographs of coxa plana patients These changes i e irregularities of the proximal surface of the metaphysis were all of the same type but varied in degree from case to case They were often marked in

III REVIEW OF THE LITERATURE

CLINICAL AND RADIOLOGICAL INVESTIGATIONS

Till late in the nineteenth century the understanding of juvenile diseases of the hip was limited to congenital luxation and coxitis From the latter heterogeneous group disorders of a non inflammatory nature were however *distinguished even before the introduction of radiological methods of in* vestigation In 1881 FIORANI described a typical deformity of the proximal end of the femur which HOFMEISTER in 1894 gave the name of coxa vara In 1897 MANDL described two cases of arthritis deformans in adolescents During the next few years a large number of reports on arthritis or osteoarthritis deformans coxae juvenalis were published Those of HOFFA (1901) v BRUNN (1903) NEGRONI (1905) PREISER (1907) FRANGENHEIM (1909) and BIBERGEIL (1910) may be mentioned in this connexion because the descriptions and the illustrations suggest that some of these cases probably were coxa plana

In 1909 SOURDAT published a study on diseases of the hip joint From a large material he was able to distinguish 8 cases showing typical clinical symptoms and radiological signs These cases by SOURDAT listed as coxa vara seem to have been coxa plana as judged on the basis of the description and the drawings

In the same year (1909) H WALDENSTRÖM described a disease which he called »der obere tuberculose Collumherd» On the basis of 10 cases *he summarized certain clinical and radiological features which still apply* in the main to coxa plana Owing to the fact that all these patients responded positively to tuberculin WALDENSTRÖM regarded the disease as tuberculous in nature The next year (1910) WALDENSTRÖM described the disorder in greater detail He still regarded it as tuberculous but he concluded »Der obere Collumherd ist also eine so charakteristische Erkrankung dass sie eine selbständige Gruppe der tuberculosen Coxitiden bilden kann»

In 1910 the American LEGG the Frenchman CALVÉ and the German PERTHES independently of each other described a non tuberculous disease

of the hip in children which they had detected and studied during the preceding years. Both the clinical picture and the radiological course of the disease were similar in the three reports and typical of coxa plana. Thus the disorder may be said to have been definitely recognized as a separate clinical entity.

Legg's first paper called »An obscure affection of the hip joint» was based on 5 cases with signs of a disease which he found was not typical of any condition previously described. He gave the following list of characteristic symptoms: age 5 to 8 years, a history of injury, limping, absence of pain, absence of constitutional symptoms, little or no spasm, absence of shortening of the limb. The radiological changes consisted of flattening of the femoral head, an irregular translucent area near the epiphyseal line, shortening and thickening of the femoral neck.

Under the name of »Pseudocoxalgie» Calvé described 10 cases of a disorder of the hip which he could not refer to tuberculous coxitis or any other disease of the hip previously known. The most typical clinical and radiological symptoms recorded were: age 3½ to 10 years, chronic or subacute joint symptoms with pain, a limp and reduced mobility of short duration and signs of rickets. The radiographs exhibited flattening of the epiphysis with two or more ossific centres, hypertrophy of the neck of the femur, coxa vara in some cases, intact joint cartilage. The cases healed with preserved mobility.

Perthes' first report included 6 cases of the disease, which he called »arthritis deformans juvenilis». He, too, emphasized the occurrence of a limp with or without joint pain and limitation of mobility as the main clinical symptoms. As the first radiological sign discernible he mentioned flattening of the femoral epiphysis and subsequent deformation, frequently cone shaped.

In 1913 Perthes published a second investigation, »Ueber Osteochondritis deformans juvenilis», in which 15 new cases were described in addition to the 6 earlier ones. He characterized the disease as »ein durch subchondrale Destruktionsherde bedingter, im Laufe von Jahren sich vollziehender eigenartiger Schwund der oberen Femurepiphyse». The clinical and radiological pictures tallied with his previous observations. Perthes discussed Waldenström's (1909, 1910) reports and stated that according to his opinion the »upper tuberculous focus in the collum» described by the latter was osteochondritis deformans juvenilis.

The above mentioned first reports were followed by a copious number of papers in which various aspects of coxa plana were discussed. A large

proportion of these papers were short case reports Among the more important articles those of LEVY (1911) SCHWARZ (1914) DREHMANN (1914) BRANDES (1914) LEGG (1916) TAYLOR & FRIEDER (1916) and PHEMISTER (1921) may be mentioned On the basis of a case in which the focus in the femoral head was curetted the last mentioned author described the disease histologically as bone necrosis

In 1920 SUNDT published a monograph under the name of »Malum coxae Calve-Legg Perthes« in which various aspects of the disorder were discussed on the basis of 66 cases

WALDENSTROM in 1922 reported a series of 22 cases which he had followed from the onset till the completion of healing On the basis of his observations he presented his well known classification of the different stages of the disease

STRÄHLL, likewise in 1922 published a survey of the disease and reported his own observations on) cases

RIEDEL (1922 1923) and AXHAUSEN (1923) described the results of histological investigations

In a study on non tuberculous diseases of the hip FROELICH (1923) reported 7 cases of coxa plana

In 1924 a monograph by MOLLER based on clinical and radiological investigation of 74 cases was published

CAAN in 1924 published an extensive survey mainly based on previous reports by other investigators KIDNER (1926) and ROCKEMER (1927) described the results of histological studies which revealed necrosis without any signs of inflammation

In 1931 FERGUSON & HOWORTH reported observations made in connexion with arthrotomy and drilling of the femoral epiphysis in 21 patients In the early stage of the disease the synovial membrane was thickened soft and vascularized In addition villus formations oedamatous and thickened periosteum and normal joint cartilage were found The authors considered the changes to be suggestive of inflammation HOWORTH (1948) was [illegible] le to confirm his previous observations in connexion with 50 later ope[illegible] ions HAYTHORN (1949) who examined the tissues removed from the ep[illegible] s of pat[illegible] operated upon for coxa plana observed aseptic necrosi[illegible] one marrow [illegible]

(1949) re[illegible] e results of a follow up inves[illegible] n 153 coxa plan[illegible]

[illegible] ECK disc[illegible] pathogenesis of coxa plana [illegible] sed on 300 c[illegible] 1950 and 1951 a and b)

In 1953 JONSATER published a study based on 34 cases representing different stages of the disease investigated by needle biopsy and 40 cases examined by arthrography of the hip joint JONSATER summarized his results as follows

The disease reaches its climax during the initial stage which roughly speaking implies total necrosis of the epiphysis Since haemorrhages do not occur the necrosis is ischaemic by nature In this stage the epiphysis is soft The radiological fragmentation stage is histologically a reparative stage during which the dense areas on the radiographs correspond to necrotic bone and the translucent areas to ingrowing reparative tissue and fresh not yet fully mineralized bone The epiphysis is harder than in the initial stage The radiological reparative stage is also histologically a regenerative phase which differs only in degree from the fragmentation stage The epiphysis is harder than in the fragmentation stage

HELBO (1953) too published a monograph on coxa plana which was based on clinical and radiological investigation of 204 cases Of these 66 were treated by protracted bed rest They were compared with symptomatically treated or untreated cases The end results in the first mentioned group were very good

In 1954 GOFF s large monograph on Legg Calve Perthes syndrome was published in which heredity constitutional aspects growth phenomena and methods of treatment are discussed at length The end results in 65 cases are reported

In the same year PERTTILA reported the results of a follow up investigation of 33 cases seen from 10 to 20 years after the active phase of the disease

In 1957 RYDER *et al* reported a series of 104 cases and KATZ described the end results in 100 cases

EVANS in 1958 published the results of a follow up study of 48 cases of coxa plana

WANSBROUGH *et al* (1959) reported their observations on a series of 129 cases and O GARRA (1959) the results of 25 cases

The most recent contributions to the clarification of the clinical and radiological aspects of the disease have been published by PONSETI & COTTON (1961) RALSTON (1961) BERGSTRAND & NORMAN (1961) GOFF (1962) and MOSE (1964)

Radiological evaluation of end results EYRE BROOK (1936) SJOVALL (1943) and HEYMAN & HERNDON (1950) used various methods for the measurement of height flattening and increase in breadth of the femoral head as compared

with the unaffected side The results were expressed as epiphyseal index epiphyseal quotient or comprehensive quotient

Regarding all these methods of measurement GOFF (1954) emphasized the difficulty in defining the points of determination In addition he pointed out that they are of no use in bilateral cases as was also emphasized by HELBO (1953)

GOFF evaluated the shape of the femoral head on direct inspection of the radiograms He classified the results as *spheroidal type mushroom type* and *irregular type* (*malum coxae juvenilis*) As an aid in determining the spherical outline of the head he used a protractor by scratching circles at 2 mm intervals on a piece of transparent acetate

MOSE (1964) estimated the shape of the outline of the head in the same way as GOFF and completed this estimate with calculation of the epiphyseal quotient as suggested by SJOVALL *Good results* meant that the head was spherical the outlines in the frontal and lateral views constituting circles with identical radii and that the epiphyseal quotient was above 60 per cent *Fair results* implied that the head was spherical but crescent shaped and flattened with an epiphyseal quotient below 60 per cent *Poor results* comprised all those heads in which the radii of the outline circles differed in the lateral and frontal views and all heads which were not spherical irrespective of the quotient

AETIOLOGY AND PATHOGENESIS

The authors of the first reports on coxa plana differed in their opinions regarding the aetiology of the disease WALDENSTROM considered it to be a mild form of tuberculosis LEGG believed that it was due to trauma CALVE who detected signs of rickets in some of his patients regarded the latter disorder as a possible cause of coxa plana PERTHES suggested the possibility of an infectious aetiology

Trauma

Necrosis of the femoral head resembling coxa plana is relatively frequent after closed reduction of a congenitally luxated hip This has been emphasized by many authors as evidence of a traumatic aetiology of coxa plana (EDEN 1912 BIBERGEIL 1912 BADE 1913 BRANDES 1916 LEGG 1916 REHBEIN 1922 HOWORTH & SMITH 1932 LIMA ESTEVE & TRUETA 1960 and others)

After traumatic luxation necrosis of the femoral head has been described by ELMSLIE (1919) REHBEIN (1923) NICOLAYSEN (1931) DYES (1935) BLUMENSAAT (1936) GOLDENBERG (1938) LINDEMANN (1957) ULLOA (1963) and others

In adolescents necrosis of the femoral head following fracture of the neck has been reported by a number of investigators e g AXHAUSEN (1922) REHBEIN (1923) JOHANSSON (1927) KRAFT (1931) LANGE (1932) BORNEBUSCH (1940) BRAILSFORD (1943) BERNBECK (1951 b) and RATLIFF (1962) These authors regarded their observations as evidence in favour of a traumatic aetiology

HELBO surveyed the cases previously reported in which trauma had been indicated as the cause Trauma was mentioned in a third of 258 case reports In the histories of 22 per cent of his own patients HELBO detected trauma of a kind that might have had a causal relationship with the onset of the disease He regarded trauma as a possible cause of coxa plana

Inflammatory causes

After WALDENSTROM and PERTHES many authors have suggested the possibility that coxa plana is due to inflammation DREHMANN (1914) PHEMISTER (1921) BERNBECK (1951 b) HOLLANDER (1952) and others have described conditions resembling coxa plana in connexion with inflammatory processes in the hip region in particular CALVE (1910) and SUNDT (1949) observed coxa plana in association with rheumatoid arthritis SINDING-LARSEN (1915) AXHAUSEN (1922) RIEDEL (1923) and HOWORTH (1948) described coxa plana in connexion with infections such as tonsillitis scarlatina and influenza JACOBS (1960) reported a study of 25 patients with synovitis in the hip joint In 3 of these the disease later developed into coxa plana He suggested a causal relationship between synovitis and osteochondrosis as a reasonable hypothesis

Hereditary and constitutional factors

A large number of authors have reported a familial occurrence of coxa plana e g CALVE SCHWARZ BRANDES (1920) SUNDT (1949) and MONTY (1962) STEPHENS & KERBY (1946) were able to trace coxa plana through five generations in the same family They found the disease in 28 out of 63 members investigated and regarded their results as indicative of inheritance according to Mendel s law

JEQUIER & FREDENHAGEN (1948) described a family in which coxa plana could be traced through seven generations In 14 cases the diagnosis was verified These authors regarded their observations as evidence of a dominant hereditary aetiology

Among 200 patients with coxa plana HELBO (1953) detected 3 5 per cent who had close relatives suffering from this disease On comparison of the frequency of coxa plana with the frequency of its familial occurrence he concluded that the difference was significant and that the large number of familial cases could not be due to chance

GOFF (1954) found a family history of coxa plana in 20 per cent of his 103 cases From his own investigation and the data available in the literature he drew the conclusion that coxa plana is a mostly recessive seldom dominant condition with varying penetrance

In a series comprising 129 cases WANSBROUGH *et al* (1959) noted a family history of coxa plana in 9 3 per cent These authors considered the disease to be of constitutional origin and believed that minor traumata and systemic infection may perhaps precipitate the onset

Coxa plana was observed in monozygotic twins by GOFF (1954) GIANNESTRAS (1954) SODERBERG (1957) WANSBROUGH (1959) DUNN (1960) and INGLIS (1960)

GOFF was able to demonstrate growth inhibition in his patients inhibition of the longitudinal growth of the lower extremities in particular Furthermore he observed delayed skeletal age in connexion with coxa plana

RALSTON (1961) reported that the bone age in his series was delayed by an average of 1 year and 9 months

MAU & SCHMITT (1960) suggested that constitutional dysostotic factors may be responsible for the development of coxa plana

Endocrine factors

Radiological changes of the hip joint resembling those seen in coxa plana were described in cretins by BIRCHER (1909) and LAWEN (1909) LOOSER (1929) regarded these changes as due to a retarded transformation of cartilage to bone ALBRIGHT (1938) reported favourable results with thyroid medication in similar cases

SUNDT (1920) suggested that the cause of coxa plana is osteodystrophy due to hereditary endocrine factors and that the onset of the disease is precipitated by trauma or infection

Thyroid function was studied by GILL (1943) in 20 children with coxa plana by KATZ (1955) in 32 children by CHAPMAN (1956) in 10 children and by BEILER & LOVE (1956) in 22 In none of these investigations was hypothyroidism observed

HOWORTH (1948) found that the basal metabolism was normal in patients with coxa plana

Nutritional factors

CALVE (1910) regarded rickets as a possible cause of coxa plana SUNDT (1920) reported that a third of his patients had a history of rickets GOFF (1954) tested patients with osteochondrosis for alkaline phosphatase and serum cholesterol without being able to detect any significant changes

SCHNEIDER (1937) demonstrated a decrease in vitamin A in children with coxa plana

BRAILSFORD (1948) stated that Legg Perthes disease is much more common among the poor than among the well to-do classes PEIĆ (1962) observed a relatively higher incidence of coxa plana among the children of manual workers By contrast GOFF (1954) detected no relation to economic levels or to housing or home environment

PONSETI (1956) suggested that the disease is due to changes in the chemical composition of the ground substance of the epiphyseal plate In biopsy specimens of the epiphyseal plate of patients with coxa plana and epiphysiolysis he observed changes resembling those seen in rats fed with a diet rich in aminonitrile WOROBEC & NORWOOD (1956) arrived at similar conclusions regarding the cause of coxa plana

Dysplasia of the acetabulum

BRANDES (1920) CALOT (1921) JANSEN (1923) and HILGENREINER (1933) attributed coxa plana to congenital changes of the hip joint In support of this view BRANDES described cases in which coxa plana developed in the unaffected hip in children with congenital luxation Later many authors (e g GUILDAL 1930 MORVILLE 1930 1935 WALDENSTROM 1934 SEVERIN 1942 HELBO 1953) have shown that coxa plana occurs in previously entirely normal hips

Racial factors

GOFF (1954) reported that coxa plana is rare in Negroes Indians and Polynesians

Circulatory factors

Many authors have suspected that disturbed circulation in the proximal end of the femur is the cause of coxa plana Mention may here be made of AXHAUSEN s (1922) theory concerning »bland mycotic embolism»

BERNBECK (1954) regarded coxa plana as osteonecrosis due to total infarction resulting from blockage of the epiphyseal vessels in the cartilage canals in the chondroepiphysis He presumed that trauma or infection may lead to degenerative cartilaginous oedema resulting in obstruction of the canals and arrest of the circulation and that the borderline lamella between the cartilage and the bone is then penetrated so that the acid cartilaginous fluid makes its way into the bone tissue and causes decalcification a chemical osteonecrosis

The investigations by TRUETA (1956 1957) regarding the supply of the proximal end of the femur are interesting in this connexion After injection of contrast medium into autopsy material and on the basis of sections and microradiographs he studied the circulation in 46 cases from the eighth foetal month to 17 years It emerged that the vessels in the ligamentum teres do not participate in the supply of the femoral head from birth until the age of 4 years and that the blood flow through the ligamentum teres is of no importance for the supply of the femoral head until the age of about 8 years After birth the metaphyseal vessels gradually decrease in size and at the age of 4 they are of practically no importance for the supply From the age of 4 to 8 years with individual variations the femoral head is exclusively supplied via the lateral epiphyseal vessels These are exposed to compression by the strong lateral rotator muscles and in extreme positions the limit of elasticity of the vessels may be exceeded TRUETA accepts trauma as a precipitating cause but emphasizes that the nutritional conditions in the femoral head at the coxa plana age are the primary cause of the disease As further evidence for this theory he points out that in a study on the vascular conditions in the proximal end of the femur in Negro children of the same age he found that the supply of the femoral head in this race occurs via the ligamentum teres earlier in life than in the white race This would explain the rare occurrence of the disease in Negro children

The investigations by ULLOA (1962) regarding the blood supply in the proximal end of the foetal femur confirms TRUETA s results

The most recent contribution to research on the circulation in the proximal end of the femur is a paper by HIPP (1962) who studied this problem on the basis of angiographies in a normal series and in different pathological condi-

tions In coxa plana he observed partial obstruction of the proximal nutrient vessels of the femoral head and relatively frequent obliteration of the ramus profundus of the medial circumflex femoral artery During the progressive stage of the disease in particular the blood flow in these vessels was retarded

EXPERIMENTAL INVESTIGATIONS

Experiments on animals have been performed in order to produce necrosis by blocking or dividing the vessels supplying the femoral epiphysis

ISELIN (1918) divided the ligamentum teres in young dogs without any necrosis resulting NUSSBAUM (1923) divided the ligamentum teres and the periosteum around the femoral neck in young dogs The experiments resulted in necrosis of the head of the femur BENTZON (1926) injected alcohol into the area surrounding the metaphysis in young rabbits and goats A condition was caused which histologically resembled coxa plana BERGMANN (1927) and MILTNER & HU (1933) brought about necrosis of the femoral head in rabbits the former by removing and the latter by dividing the periosteum of the femoral neck and by dividing the ligamentum teres

LEMOINE (1957) induced necrosis of the head of the femur in rabbits by division of the ligamentum teres division of the nutrient vessels to the head and division of the anterior circumflex artery

ROKKANEN (1962) was able to produce necrosis of the femoral head in rabbits *e g* by tightly ligating the neck with steel wire and by dividing the ligamentum teres

A LANGENSKIOLD *et al* (1962) studied the changes following experimental dislocation of the hip in young rabbits After closed reduction of such hips necrosis of the head and the neck of the femur was observed

NAGURA (1937) and NAGURA & KOSUGE (1938) induced changes resembling coxa plana in rabbits by local blunt trauma of the femoral head From his experimental results NAGURA drew the conclusion that an aseptic necrosis is always primarily due to a subchondral fracture

NORMAL GROWTH OF THE PROXIMAL END OF THE FEMUR

Ossification of the femur begins in the seventh foetal week with ossification of the diaphysis At birth or immediately after an ossific centre develops in the distal end of the bone In the proximal end of the femur the epiphyseal plate in the newborn child forms a coherent, crescentic line The medial portion of the epiphyseal plate is transformed into the subcapital

epiphyseal cartilage which forms the growth zone of the femoral neck. Initially the neck grows almost straight in the cranial direction but soon the lateral portion of the pre plate also develops into the epiphyseal cartilage of the greater trochanter. Growth and modelling of the proximal end of the femur from now on occurs by reciprocal action of these two separate growth zones (MORGAN & SOMERVILLE 1960). The first effect of growth in the area of the trochanter is a decrease of the valgus position and increased growth of the proximolateral part of the bone. In the subcapital epiphysis an ossific centre develops in girls at the age of three to four months and

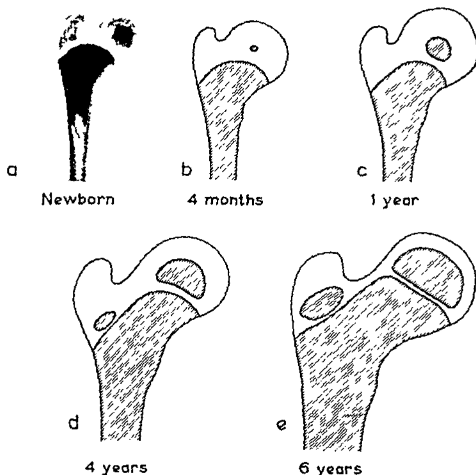


Fig. 1. The transformation of the preplate to separate growth zones for the femoral head and the greater trochanter. The development of the epiphyseal nuclei in the proximal end of the femur. *a* radiogram of the proximal end of the femur of a still born foetus (female) weighing 3250 g. *b—e* drawings made on the basis of radiograms

in boys at the age of five to six months. In the greater trochanter an ossific centre develops at the age of about four years (SCHMID & HALDEN 1949).

Fig. 1 demonstrates the transformation of the pre-plate, its division into two separate epiphyseal plates and the development of the ossific centres in the femoral head and the greater trochanter.

At the Orthopaedic Hospital of the Invalid Foundation investigations by the tetracycline method are in process regarding the growth of the proximal end of the femur in pigs. These studies have shown that the growth of the greater trochanter occurs in equal parts in the metaphysis and by apposi-

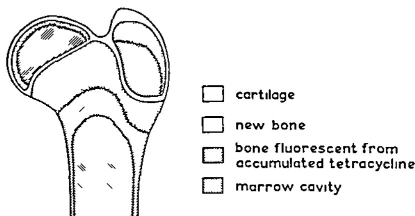


Fig. 1. Drawing of a frontal section through the upper end of the femur of a 14 week old pig injected eight weeks previously with tetracycline (50 mg/kg).

tion around the tip of the greater trochanter. The growth of the femoral neck occurs in the metaphysis and is markedly stronger than the growth of the subtrochanteric region. By contrast, apposition is markedly weaker in the capital epiphysis than in the greater trochanter (A. LANGENSKIÖLD & SALENIUS, unpublished observations). (See Fig. 2.)

TREATMENT

Previously the treatment of active coxa plana consisted in purely symptomatic measures: immobilization and/or weight relief by bed rest, by traction or by the use of plaster casts for some period of time (SCHWARZ 1914, BRANDES 1920 and others). Some authors, *e. g.* PERTHES (1913), CALVÉ

(1910) and NIEBER (1916) preferred early mobilization CAAN (1921) and SUNDT (1949) maintained that the course of the disease and the end results could not be influenced to any appreciable degree by any kind of treatment

Later the importance of protracted non weight bearing has been generally accepted but owing to the long duration of the disease adequate accomplishment of such treatment meets with considerable difficulties Practical and social viewpoints have therefore determined the principles on which it is carried out

WALDENSTROM (1923) introduced a compromise therapy bed rest and traction only in cases where pain and contracture were present otherwise weight relief by crutches or splints Different modifications of this treatment have been used by SEVERIN (1942) LEVY & GIRARD (1942) MINDELL & SHERMAN (1951) EVANS *et al* (1958) WANSBROUGH *et al* (1959) and others

BRAILSFORD (1932 cited by BRAILSFORD 1948) and DANFORTH (1934) reported good results after prolonged bed rest This method in combination with different kinds of traction and continued by weight relief accomplished with crutches or splints has later been employed by a large number of authors *e g* EYRE-BROOK (1937) GILL (1940) SJÖWALL (1943) HERNDON & HEYMAN (1952) HELBO (1953) GOFF (1954) RATLIFF (1956) RYDER *et al* (1957) O GARRA (1959) HOWORTH (1959) JACOBS (1960) RALSTON (1961) and MOSE (1964)

Duration of treatment Since DANFORTH in 1934 recommended non weight bearing for three to four years views have changed somewhat on this point Many modern authors regard one and a half to two years weight relief as adequate HAUGE (1956) treated his patients by non weight bearing for one year but after comparison with the end results in series treated in the same way for longer periods he recommended weight relief for one and a half years In his first study (1954) GOFF reported that the mean non-weight-bearing period in his series had been 27 months but later (1959) he reduced this time to nine months combined with crutch walking for further six months EVANS (1958) used an average of 25 months non weight-bearing

Regarding the treatment of bilateral cases the majority of authors — even those who prefer ambulatory treatment in unilateral cases — consider hospitalization to be the only possible alternative Bed rest is continued until either hip is trusted to tolerate weight bearing and then the patient is allowed to walk with the worse side in a caliper (MINDELL & SHERMAN 1951 WANSBROUGH *et al* 1959 and others) MCKENDRY *et al* (1960) described a brace for the treatment of bilateral cases of coxa plana which they had used

successfully GRIPENBERG & WALLGREN (1963) reported good results with Thomas splints in bilateral coxa plana

Previously operative treatment was only resorted to in poorly healed cases in part as a remodelling measure in part in the form of resection of the femoral head or osteotomy for the correction of malposition (CAAN 1924)

FREUND (1922) described 3 cases of severe deformation after coxa plana with positive Trendelenburg signs in which he successfully excised the joint capsule ventrolaterally removed osteophytes by chiselling and shifted the greater trochanter a couple of centimetres in the distal direction

In more recent years various procedures have been employed in order to damage the necrotic epiphysis and thus bring about its revascularization and more rapid healing BOZSAN (1932) FERGUSON & HOWORTH (1934) v ABERLE HORSTENEGG (1941) HOWORTH (1948) DUBOIS (1951) and KIENZLE (1953) used drilling of the epiphysis through the greater trochanter or the femoral neck Drilling and grafting were used by HACKENBROCH (1941) STUPNICKI (1952) BERTRAND (1954) CAMARGO (1957) and YAMAGUCHI (1959) BERNBECK (1948) and GARDEMIN (1951) evacuated the necrotic portion of the epiphysis CATHRO & KIRKALDY WILLIS (1963) plugged the evacuated epiphysis with spongy bone from the femoral neck or the crista iliaca and PITZEN (1951) PETER (1955) and SALVO LECARRE (1957) drove a metal nail into the epiphysis through the greater trochanter and the femoral neck

Subtrochanteric osteotomy was employed by SOEUR & DE RACKER (1952) and SLAVIK (1956) in order to alter the weight bearing surface of the epiphysis

With regard to medication accelerated healing with thyroid preparations has been reported by EDBERG (1918) MOLLER (1921) CAVANAUGH *et al* (1936) EMERICK *et al* (1954) FIELDS (1959) and others while PONSETI & COTTON (1961) observed no effect of thyroid medication

GOFF (1954 1959) used aureomycin and achromycin in coxa plana in order to promote growth

Androgenous and oestrogenous hormones in combination with thyroid preparations were administered by GLERITER *et al* (1959) KOSKINEN (1959) who noted a significant effect of human growth hormone and thyrotropin on the healing of fractures in laboratory animals suggested the use of this treatment also in aseptic necroses KRISTENSEN (1963) recommended anabolic steroids in the treatment of coxa plana

IV MATERIAL AND METHODS

MATERIAL

The material consists of all cases of coxa plana registered at the Radiological Department of the Orthopaedic Hospital of the Invalid Foundation during the years 1946—1958 The total number of cases is 276 Fifty of these were bilateral and the total number of affected hips is thus 326 The series includes 22 patients who were adult at the time of their first visit In these cases the process had already reached its final stage The annual number of registrations is shown in Table 1

TABLE 1 — *Annual number of patients with coxa plana registered at the Orthopaedic Hospital of the Invalid Foundation during the years 1946—1958 (total 276)*

Year	No of cases	Adult at the first examination
1946	6	2
1947	3	—
1948	7	—
1949	23	5
1950	23	4
1951	32	2
1952	28	—
1953	21	2
1954	35	1
1955	28	3
1956	18	—
1957	23	2
1958	29	1
Total	276	22

Of the present cases 246 had been remitted to the Radiological Department from the Outpatient Department of the Orthopaedic Hospital and 30 from the private practices of the doctors on the hospital staff

The distribution of the cases geographically and according to residence and family environment is seen in Tables 2, 3 and 4.

The small number of cases registered during the first three years (Table 1) is accounted for by the exceptional conditions prevailing after the war when the work in this hospital mainly consisted of the care of the war wounded and the means of communication were deficient.

Table 2 shows that the geographical distribution of the coxa plana pa-

TABLE 2. — *Geographical distribution of 274 cases of coxa plana compared with the distribution of the whole population in Finland in 19[illegible]*

Province	Coxa plana		Whole population
	No. of cases	%	%
Nyland (Uusimaa)	63	23.0	17.0
Åbo & Björneborg (Turku & Pori)	37	13.3	15.5
Åland (Ahvenanmaa)	1	0.4	0.5
Tavastehus (Häme)	41	15.0	13.5
Kymmene (Kymi)	24	8.8	8.0
St. Michel (Mikkeli)	20	7.3	6.0
Kuopio	29	10.6	11.5
Vasa (Vaasa)	26	9.5	15.0
Uleåborg (Oulu)	21	7.7	9.0
Lappland (Lappi)	12	4.4	4.0
Total	274	100.0	100.0

tients corresponded fairly well with the distribution of the whole population over the different provinces of Finland. A slight preponderance of patients from the provinces of Nyland and Tavastehus is accounted for by proximity to the capital. The relatively smallest number of patients had been remitted

TABLE 3. — *Distribution of 74 cases of coxa plana according to residence, compared with the corresponding distribution of the whole population in 1952*

Residence	Coxa plana		Whole population
	No. of cases	%	
Towns and market towns	98	35.8	34.0
Rural districts	176	64.2	66.0
Total	274	100.0	100.0

TABLE 4 — *Distribution of 64 cases of coxa plana according to social background compared with the corresponding distribution of the whole population in 1950*

Father s occupation	No of cases	% of cases	Distribution of children in the whole population according to father s occupation
Workers	127	48	43
Farmers	71	27	36
Clerical or non manual managerial/professional	66	25	21
Total	264	100	100

from the province of Vasa (9 5 per cent against 14 6 per cent) This is due to the fact that two specialists on orthopaedics were practicing in this province during a great part of the time the present series was collected

As is seen in Table 3 the present study did not reveal any difference in the frequency of coxa plana between the rural and urban populations

In this series no particular social group seemed to be especially affected with coxa plana (Table 4)

METHODS

Clinical examination

The patients remitted from the Outpatient Department were clinically examined there As a rule gait and Trendelenburg s sign mobility of the hip joints and the length of the lower extremities were recorded In addition the erythrocyte sedimentation rate was determined in many cases and in some the protein bound iodine in serum No other laboratory tests were regularly performed The data regarding these examinations were obtained from the records of the Outpatient Department which unfortunately in many cases were incomplete

The clinical data regarding the private patients were obtained from the respective doctors In some cases I examined the patients myself

When the material was collected in 1956 I found that no less than 148 patients had to be summoned to follow-up examinations The majority of these had visited the Outpatient Department but failed to attend at the follow up examinations In a minor proportion of cases the treatment had been regarded as finished Of the 148 patients 100 attended at follow up investigations during the years 1958—1961 In about 10 cases no contact could be established and the remainder failed to attend

Radiological examination

All patients were radiologically examined Among the earliest cases there are some in which radiographs were taken in only one projection and a few where only the affected hip was examined

On radiological examination of a chronic disease of the hip such as coxa plana which necessitates repeated check-ups it is of paramount importance that a standardized method is employed so that the results of one examination are comparable with those of the next Since 1946 a modification of the method suggested by KNUTSSON (1938) has been used in the radiological examination of the present patients as well as in other examinations of the hip performed in this Department As a rule both hips are simultaneously radiographed on the same film Frontal views are taken with the patient supine with the legs extended in 20 degrees inward rotation In this position the neck of the femur is parallel with the film broadly speaking since according to v LANZ (1950) the antetorsion angle of the femoral neck is about 20 degrees in the coxa plana age

Lateral views are also taken with the patient supine with about 25 degrees flexion and 50—60 degrees abduction of the femora which are supported with wedges of sponge plastic The knees are bent and the feet placed against each other in the median line A maximum of symmetry is aimed at If the pelvis is slanting owing to atrophy of the gluteal muscles this is corrected with cushions The central ray is focussed immediately above the symphysis The target — film distance is 110 cm

In cases with contracture of the hip joint in which limited abduction makes a simultaneous examination of the two hip joints impossible in the lateral projection these are separately studied By keeping the pelvis aslant the desired position is achieved

The radiographs obtained by this technique have proved satisfactory

During the period of non weight bearing treatment check up examinations were made at intervals of three to four months in some cases at shorter intervals In a large number of cases the intervals between the check ups were much longer owing to failure of the patient to attend at the time arranged During the last few years this drawback has been eliminated to a great extent thanks to the work done in our hospital by nurses specially trained in social care

The first follow up examination after the completion of non weight bearing treatment was made after four to six weeks Subsequently the intervals between the examinations were gradually prolonged to one and two years at the time of completed growth

TABLE 4 — *Distribution of 264 cases of coxa plana according to social background compared with the corresponding distribution of the whole population in 1950*

Father's occupation	No of cases	% of cases	Distribution of children in the whole population according to father's occupation %
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In order to facilitate assessment of the shape of the femoral head the plastic protractor seen in Fig 3 was used

With the protractor placed on the radiograph the fit of the femoral head in one of the circles was estimated If the head was spherical the length of the radius was measured In unilateral cases the same procedure was carried out on the unaffected side

Furthermore the length of the femoral neck and the breadth of the meta physis were measured in both hips in unilateral cases

V CLINICAL AND RADIOLOGICAL OBSERVATI

GENERAL CONSIDERATIONS

Sex distribution Table 5 shows the sex distribution in the present
The ratio males to females is 4 1

TABLE 5 — *Sex distribution in 276 cases of coxa plana*

	No of cases	%
Males	223	80 8
Females	53	19 2
Total	*276*	*100 0*

Affected side The distribution according to affected hip in this seri
shown in Table 6

TABLE 6 — *Distribution according to affected side in 276 cases of coxa plana*

Sides	Males		Females		Total	
	No of cases	%	No of cases	%	No of cases	
Right	84	37	21	40	105	38
Left	97	44	24	45	121	44
Both	42	19	8	15	50	18
Total	223	100 0	53	100 0	276	100 0

Body build The body build was subjectively assessed by inspection in 215 cases The results are seen in Table 7

In the cases exhibiting obesity the sella turcica was radiologically examined No pathological changes were observed

TABLE 7 — *Body build in 215 cases of coxa plana*

	No of cases	%
Normal	183	85.1
Slender	24	11.2
Stout	8	3.7

TABLE 8 — *Age at onset in 265 cases of coxa plana*

Age in years	Males	Females	Total	%
2— 3	6	6	12	4.5
4— 5	61	10	71	26.8
6— 7	82	22	104	39.3
8— 9	41	8	49	18.5
10—11	21	5	26	9.8
12—14	3	—	3	1.1
	214	51	265	100.0

Age at onset The patient s age at the time when the first symptoms — a limp and/or pain — were observed was regarded as the onset age. [illegible] could be established in 265 cases as shown in Table 8

The youngest patient was 2 years and 8 months and the oldest [illegible] years old at the time of onset of the disease

It is noteworthy that the ratio males to females is 1 1 in the [illegible] age group The small number of cases does not allow of any [illegible] however

In 11 cases the age at onset could not be established

Duration of symptoms The duration of symptoms at the [illegible] gnosis was calculated from the onset If the diagnosis had [illegible] some other hospital and adequate treatment had been instituted [illegible] of time was regarded as the limit of the duration of symptoms [illegible] treatment had not been instituted elsewhere this period [illegible] to the time when the disease was diagnosed in our Hospital [illegible] the duration of symptoms in the present series

Twenty two ultimately healed cases are omitted from Ta[illegible] duration groups consist of neglected cases the major[illegible] very advanced stage of reconstruction when first ex[illegible] the table that treatment had been instituted within [illegible] onset of symptoms in less than half the cases

TABLE 9 — *Time from onset of symptoms to diagnosis in 254 cases of active coxa plana*

Duration of symptoms in months	No of cases	%
0—1	39	15.4
2—3	43	16.9
4—5	28	11.0
6—7	39	15.4
8—12	32	12.6
13—24	49	19.3
25—36	24	9.4
Total	254	100.0

Mean duration 9.6 months

Stage of the process at the time of diagnosis On the basis of the radiographic findings at the time of diagnosis the present series was divided into groups according to JONSATER's (1953) modification of WALDENSTRÖM's (1923) classification The distribution of the cases is shown in Table 10

TABLE 10 — *Distribution according to stage of the process at the time of diagnosis in the whole series*

Stage	No of hips in unilateral cases	No of hips in bilateral cases	Total no of hips	%
Initial	101	46	147	45.1
Fragmentation	75	35	110	33.7
Reparative	33	8	41	12.6
Definitive	17	11	28	8.6
Total	226	100	326	100.0

The group »definitive stage» includes 6 bilateral cases In one of these the outline of one femoral head showed defects which will probably disappear later This hip was included in the group »reparative stage» If the cases in the group »definitive stage» are omitted the cases diagnosed in the initial stage constitute only 48.3 per cent of the series

TREATMENT

At the Orthopaedic Hospital of the Invalid Foundation coxa plana has been conservatively treated The main principle of treatment has been the prevention of weight bearing on the affected hip In unilateral cases weight

relief has been accomplished with Thomas splint and elevation of the opposite shoe In bilateral cases where non weight bearing on both hips has been conditional this has been secured by bed rest One of the present patients was treated by bilateral Thomas splints Until 1957 patients were hospitalized only if the diagnosis was uncertain or if the joint exhibited marked contracture Since 1957 the pattern of treatment has been as follows Hospitalization for three to eight weeks during which the patient was kept in bed Traction was used if contracture of the hip was present A Thomas splint was manufactured fitted and adjusted Towards the end of the hospitalization period the patient practiced walking with the splint the fit of which was further adjusted When the patient had learned to walk with a Thomas splint he was discharged and his parents were informed as to the importance of strictly following the prescriptions regarding the use of the splint Subsequent follow up examinations were done at the Outpatient Department Exceptions from this routine were made in 1958 in particular when unfortunately for certain administrative reasons admission to the hospital was difficult in many cases

Table 11 shows the kind of treatment prescribed in the present cases The first group comprises the patients registered during the first few years covered by this study and some bilateral cases from more recent years At a later follow up examination of these cases it was found that the treatment prescribed had often been so inadequately carried out that no major influence on the course of the disease can be accorded to it These cases were classified as untreated (cf p 41)

TABLE 11 — *Treatment prescribed at the Orthopaedic Hospital of the Invalid Foundation*

	No of cases
Bed rest and/or crutch walking at home	29
Bed rest with traction at home	4
Thomas splint	190
Hospitalization + Thomas splint	27
Total	250

In a number of cases diagnosed elsewhere the patients had received some *kind of treatment as shown in Table 12 before being seen at the Orthopaedic* Hospital of the Invalid Foundation

It is seen in Table 12 that Thomas splint had been prescribed elsewhere in very few cases

TABLE 12 — *Treatment before the first examination at the Invalid Foundation*

	No of cases
Sparing use of limb crutches	22
Bed rest	44
Traction	17
Plaster cast	21
Thomas splint	8
Total	112

If the non weight bearing treatment indicated in Table 12 was regarded as adequately carried out it was included in the data regarding the duration of such treatment.

Non weight bearing treatment was continued until reconstruction had advanced so far that the radiological appearance of the epiphysis was almost uniform and a large proportion of the epiphysis showed a normalized structure on the radiographs

The duration of non weight bearing treatment is seen in Table 13

TABLE 13 — *Duration of non weight bearing in 194 cases*

Years	No of cases
1	32
1—2	85
2—3	62
3—4	14
over 4	1

Mean duration of non weight bearing 2 3 years

After the completion of non weight bearing treatment the patients were told not to strain their hips for a further two or three years or until primary healing had been achieved During this time school gymnastics and athletics were forbidden

As a rule Thomas splint was abandoned gradually being used during half the day for instance at school while the child was allowed to walk without it during the rest of the time

Not in a single case have we had to revoke the decision to let a patient abandon Thomas splint The radiological check ups invariably showed that the epiphysis had tolerated the strain Usually the very first follow up examination showed increased reconstruction

END-RESULTS

In the present study the time from the onset of the first symptoms until the last (or only) radiological examination is indicated in Table 14

TABLE 14 — *Time from onset to last or only examination in 276 cases of coxa plana.*

Years	No of cases	Years	No of cases
1	18	9	20
2	12	10	23
3	15	11	16
4	20	12	10
5	26	13	9
6	35	14	1
7	27	15	4
8	24	16 or more	16

The longest period between the onset of symptoms and the last radiological examination was 36 years

Primary healing is used in the present series to denominate the condition prevailing when the reparative process in the femoral epiphysis had advanced so far that the latter had attained its final shape and the bony structure of the epiphysis had been normalized In this stage the epiphysis was uniform provided that no loose bodies remained as in osteochondrosis dissecans

Ultimate healing is used to denominate the stage when growth was completed

Since the *shape of the epiphysis* does not change to any appreciable degree after primary healing has taken place that is during the remainder of the growing period (WALDENSTROM 1923) the cases showing primary and ultimate healing were united when the end results in the femoral head were assessed

Definition of the degree of healing The femoral head was regarded as spherical (*good result*) if its outline could be precisely fitted into one of the circles of the plastic protractor and if the radii of the circles formed by the outline on the frontal and lateral views did not differ from each other by more than 1 mm A difference of 1 mm between the radii on the frontal and lateral views was noted on the unaffected side in many cases

The femoral head was evaluated as elliptical (*fair result*) if its outline was regularly convex without fitting into any of the circles of the protractor and if the difference between the radii of the outlines on the frontal and lateral views exceeded 1 mm

The femoral head was evaluated as irregular (*poor result*) in those cases where it could not be regarded as spherical or elliptical

In the present series a total of 165 treated hips in 119 unilateral and in 23 bilateral cases showed either primary or ultimate healing

TABLE 15 — *Relationship between radiological end results and age at onset in 165 treated hips*

End results	Onset age in years											
	2—3		4—5		6—7		8—9		10—14		Total no of hips	%
	No	%	No	%	No	%	No	%	No	%		
Good	10	90.9	31	64.6	30	49.2	10	31.2	—		81	49.1
Fair	1	9.1	13	27.1	14	22.9	6	18.8	1	7.7	35	21.2
Poor	—		4	8.3	17	27.9	16	50.0	12	92.3	49	29.7
	11	100	48	100	61	100	32	100	13	100	165	100

TABLE 16 — *Relationship between radiological end results and duration of symptoms before treatment in 165 treated hips*

End results	Time in months												Total no of hips	%
	0—1		2—3		4—5		6—7		8—12		13—24			
	No	%	No	%	No	%	No	%	No	%	No	%		
Good	23	74	21	65.6	9	45	16	51.6	4	18.2	8	27.6	81	49.1
Fair	6	19.5	3	9.4	8	40	5	16.2	3	13.6	10	34.4	35	21.2
Poor	2	6.5	8	25	3	15	10	32.2	15	68.2	11	38	49	29.7
	31	100	32	100	20	100	31	100	22	100	29	100	165	100

TABLE 17 — *Relationship between radiological end results and stage of the process at the institution of treatment*

End results	Stage						No of hips
	Initial		Fragmentation		Reparative		
	No of hips	%	No of hips	%	No of hips	%	
Good	55	56.7	25	39.0	1	25.0	81
Fair	18	18.6	16	25.0	1	25.0	35
Poor	24	24.7	23	36.0	2	50.0	49
Total	97	100.0	64	100.0	4	100.0	165

In Tables 15 16 and 17 the radiological end results are correlated with onset age duration of symptoms and stage of the process at the institution of treatment

Enlargement of the femoral head In order to obtain an idea of the enlargement of the femoral head in those cases where it healed as spherical the radii of the outline circles of both heads were compared in unilateral cases To this end the cases were divided into primarily healed (42) and ultimately healed (21) In no case was the radius of the affected head smaller than that of the unaffected head In the group of primarily healed cases there were 7 with the same radius on both sides The difference between the two radii varied between 1 and 5 mm the mean being 2 6 mm In the group of ultimately healed cases one showed the same radius on both sides The difference varied between 1 and 10 mm the mean being 3 7 mm

In the primarily healed group the radii of the affected heads exhibited a mean enlargement of 11 9 per cent as compared with the unaffected heads The corresponding figure for the ultimately healed group was 13 6 per cent The corresponding mean increases in the volume of the head were 38 5 and 46 4 per cent respectively

Discussion This analysis demonstrates the well known fact that the head of the femur in a coxa plana hip as a rule is enlarged as compared with the unaffected side

In the present analysis the flattening of the epiphysis was disregarded while in the above mentioned calculations of index it has been taken into account It is very difficult however to estimate the degree of flattening of the epiphysis since the height of the latter shows a wide variation even in spherically healed cases owing to a cranially directed convexity in the metaphyseal plane In these cases the height of the epiphysis is hardly of any practical significance however It is the shape of the head that is decisive irrespective of whether it is a hemisphere consisting of the epiphysis alone or consists of a crescent shaped epiphysis the basal interior portion of which is filled out by the metaphysis

Untreated cases The present series includes both entirely untreated coxa plana hips and cases in which the treatment had been so recently instituted or so inadequately carried out that no therapeutic significance can be accorded to it The primary or ultimate healing could be evaluated in 78 such hips (67 cases) The end results are shown in Table 18

The surprisingly large number of good results in this group is accounted for by the fact that it includes 4 very slight abortive unilateral cases and 12 bilateral cases in which the better untreated hip exhibited slight abortive

TABLE 18 — *Relationship between radiological end results and age at onset in 78 untreated hips*

Onset age in years	Good	Fair	Poor	No of hips
2—3	1	—	1	2
4—5	7	1	4	12
6—7	5	5	15	25
8—9	1	2	12	15
10—11	3	—	6	9
12—14	1	1	2	4
unknown			11	11
Total	18	9	51	78
Per cent	23	11	66	100

changes Only two of the untreated cases which healed with spherical femoral heads showed fragmentation of the epiphysis

If these abortive cases are omitted the end results in the untreated group are as follows

Good 3 2 per cent Fair 14 5 per cent Poor 82 3 per cent

When these results are compared with the end results in the treated group (Table 15) the difference is striking

Cases under treatment The series includes 61 patients (83 hips) who are still under treatment or have failed to attend at follow up examinations In these cases it is not possible to say anything regarding the end result

Special factors affecting the end results

In the present series the following factors were found to affect the end-results

Osteochondrosis dissecans	in 16	cases	(3 untreated)
Subluxation	» 45	»	(30 »)
Secondary arthrosis	» 20	»	(17 »)

Comparison of the present observations with previous reports

Sex incidence The data of different authors agree in that coxa plana is commoner in boys than in girls In Table 19 the relevant figures from some of the more extensive series are indicated

TABLE 19 — *Sex incidence of coxa plana in other series*

Investigator	No of cases	Males %	Females %
Levy et al (1942)	102	91 0	9 0
Bernbeck (1951 a)	369	77 0	23 0
Sundt (1949)	153	78 0	22 0
Kite et al (1952)	165	86 0	14 0
Helbo (1953)	204	77 4	22 6
Goff (1954)	103	83 0	17 0
Ryder et al	104	82 2	17 8
Evans (1958)	52	75 0	25 0
Wansbrough et al (1959)	129	81 4	18 6
Carpenter (1960)	90	84 5	15 5
Peić (1962)	189	79 4	20 6
Mose (1964)	257	80 6	19 4

The sex incidence in the present series — 80 8 per cent males and 19 2 per cent females — is in good agreement with the figures in Table 19

TABLE 20 — *Distribution of coxa plana according to affected side in other series*

Investigator	No of cases	Right side	Left side	Both sides %
Sundt	153	40 5	47 0	12 5
Helbo survey of the literature	250	57 0	38 0	5 0
Helbo own series	204	48 0	44 6	7 4
Goff	103	42 5	40 0	17 5
Ryder et al	104	42 3	42 3	15 4
Evans	58	48 2	41 5	10 3
Wansbrough et al	129	?	?	17 8
Peić male patients	150	56 0	38 7	15 3
Peić female	39	33 4	56 4	10 2
Mose	257	?	?	10 9

Affected side The observations regarding the affected side in certain earlier series are compiled in Table 20 Most reports show a slight preponderance for the right side SUNDT had slightly more left sided than right sided cases while the two sides were equally represented in RYDER s series PEIC observed a preponderance of right-sided lesions in the male patients while the female group showed a left sided preponderance

In the present series a slight preponderance was noted for the left side i e 44 per cent against 38 per cent right sided while the proportion of bilateral cases was 18 per cent (Table 6) Contrary to PEIC s finding there was no difference between males and females in regard to the frequency of right-sided and left sided lesions

The frequency figures for bilateral cases indicated in the literature show a wide variation (Table 20) This may perhaps be accounted for by the fact that in bilateral cases the lesion in one hip is often very slight and may escape recognition for instance if satisfactory lateral views are not available

Age at onset In the present series (Table 8) there was an obvious accumula tion of cases in the age group 6—7 years which was represented by 39 3 per cent

STAHL (1948) calculated the onset age by reducing the age at the first radiological examination by an average of three nine or eighteen months depending on whether the process was in the initial fragmentation or early reparative stage at the time of the first examination According to these calculations the mean age at onset was 6 6 years in STAHL s series compris ing 103 hips In other series published the maximum frequency varies to some extent The following authors for instance have observed a peak for the age groups as listed here BERNBECK (1951 a) 8 years WANSBROUGH *et al* (1959) 7 years GOFF (1954) 6 years HELBO (1953) and PONSETI & COTTON (1961) 5—6 years O GARRA (1959) HERZOG (1961) and MOSE (1964) 5 years PEIC (1962) 4—6 years

Duration of symptoms from onset to diagnosis It is seen in Table 9 that the duration of symptoms from onset to diagnosis was an average of 9 6 months in the present series

HELBO (1953) described a group of 66 patients with coxa plana in which the duration of symptoms was an average of 3 9 months in 39 cases an average of 6 months in 6 and 10 1 months in 21 In EVANS (1958) series the duration was one to 36 months the mean being 6 months CARPENTER & POWELL (1960) indicated a mean duration of symptoms of 7 months and 24 days In a series of 107 patients with coxa plana described by RALSTON (1961) treatment could be instituted 3 months after onset in 49 cases (46 per cent) In the series described by WANSBROUGH *et al* (1959) comprising 106 cases fifty per cent were diagnosed within 3 months and in two thirds the diagnosis was made within 6 months after onset

Stage of the process at diagnosis As is seen in Table 10 slightly less than half the present cases of active coxa plana were in the initial stage at the time when the diagnosis was made 33 7 per cent were in the fragmenta-

tion stage and 15 8 per cent exhibited more or less advanced reconstruc tion

In HELBO s (1953) series of 66 patients treated by protracted bed rest 68 per cent were initial cases and 32 per cent showed fragmentation on admission to hospital WANSBROUGH *et al* (1959) described 55 5 per cent of their cases as very early or early and 44 5 per cent as advanced or very advanced Among 90 patients examined CARPENTER & POWELL (1960) found that 73 3 per cent had minimal or moderate and 26 7 per cent advanced destructive changes

End results In Table 21 the end results in a number of previous studies are compiled There are wide variations in the selection of cases the treatment employed and the methods of evaluation of the end results in both the series treated by bed rest and in those treated by various non weight

TABLE 21 — *Relationship between end results and treatment in different series reported in the literature*

Investigator	No of cases	Treatment	Results in		
			Excellent and good	Fair	Poor
Fike 1950	11	Bed rest without splints	36	28	36
Fike	23	Bed rest with splints	83	10	7
Mindell et al 1951	28	Bed rest	53 5	17 7	28 8
Herndon et al 1952	33		61 0	39 0	0
Helbo 1953	61		82 0	16 4	1 6
Goff 1954	65		57 0	29 2	13 8
Hauge 1956	132		32 6	40 0	27 4
Ratliff 1956	41		43 7	36 8	19 5
Evans 1958	52		29 0	40 0	31 0
Evans et al 1958	24		62 5	20 8	16 7
Wansbrough et al 1959	14		50 0	36 0	14 0
Herzog 1961	73		77 5	14 0	8 5
Mose 1964	78	Strict bed rest	58 0	17 0	25 0
Mose	70	Mobile bed rest	61 0	20 0	19 0
Mindell et al 1951	32	Crutches or walking caliper	72 0	15 5	12 5
Evans et al 1958	24	Crutches and Snyder s sling	58 3	16 7	25 0
Herzog 1961	34	Walking caliper	44 0	24 0	32 0
Wansbrough et al 1959	76	Taylor caliper	75 0	11 8	13 2
Wansbrough et al	16	Thomas splint	25 0	75 0	25 0
Mose 1964	71	Walking caliper	45 0	17 0	38 0

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Stage of the process at diagnosis As is seen in Table 10 slightly less than half the present cases of active coxa plana were in the initial stage at the time when the diagnosis was made 33 7 per cent were in the fragmenta-

a large number of authors emphasize that the earlier treatment is instituted the better are the results (BRANDES 1920 SEVERIN 1942 SJÖVALL 1943 MINDELL & SHERMAN HELBO GOFF WANSBROUGH *et al* CARPENTER & POWELL and others)

The present observations confirm the above mentioned observation It is seen in Table 16 that in over half of the cases which healed with a spherical femoral head treatment had been instituted within three months after the onset of symptoms while only about 15 per cent of the patients with good results had been ill for over seven months when the diagnosis was made

In the present series the mean duration of symptoms before the institution of treatment was 9 6 months (Table 9) This seems to some extent at least to account for the poorer end results in this series as compared with some of those presented in Table 21 In the majority of the earlier series a shorter mean duration of symptoms has been indicated

RALSTON (1961) arrived at deviating results in regard to the relationship between onset age and end results His series consisted of 43 cases of unilateral coxa plana Treatment (recumbency with Buck s extension and daily progressive resistance exercise) was in all cases instituted within three months after the onset of symptoms Statistical analysis of the comprehensive quotient after healing had begun showed no correlation between onset age and degree of healing The age at onset as compared with the duration of the period of recovery gave a poor correlation and the correlation between onset age and the maximal percentage of epiphyseal involvement was also poor

Stage of the process at institution of treatment and end results This point was discussed by HELBO HAUGE, WANSBROUGH *et al* and CARPENTER & POWELL among others who found that the end results were better if the treatment had been instituted before the process had advanced to the stage of fragmentation

The present series (Table 17) shows a clear tendency towards better radiological end results when treatment was instituted at an early stage of the disease

Factors affecting the end results HAAS (1937) FREUND (1939) BRAILSFORD (1943) HERMODSSON (1944) SUNDT (1949) GOFF (1954) PERTTILA (1954) RATLIFF (1956) EVANS (1958) JENKINS (1958) FREEHAFER (1960) and MORRIS & McGIBBON (1962) have described occasional cases in which a condition resembling osteochondrosis dissecans was associated with coxa plana MOSE (1964) detected 8 cases of osteochondrosis dissecans in his

series All these patients belonged to the higher age groups and in none of these cases were there any radiological changes discernible in the epiphyseal line or the metaphysis

In the present series osteochondrosis dissecans was detected in 17 hips *i e* in 5 2 per cent of the 326 hips with coxa plana examined In one bilateral case osteochondrosis dissecans was also bilateral Four of these patients belonged to the age group 5—7 years at the onset of the disease and 12 patients were 8—11 years at onset In 13 cases growth was completed In 8 there were no or minimal metaphyseal changes In 9 hips osteochondrosis dissecans developed in connexion with severe metaphyseal disturbances In this respect the observations in the present series differ from those of MOSE

In 7 of the cases under discussion there was a history of trauma The experimental investigations of A LANGENSKIOLD (1955) and TALLQVIST (1962) regarding the development of osteochondrosis dissecans lend strong support to the view that the cause of this lesion is a *cartilage fracture* during the growing period In the present series of 276 cases there were 48 (17 3 per cent) in which trauma was mentioned in the history Among those showing osteochondrosis dissecans 43 7 per cent had a history of trauma This is strongly suggestive of a causal relationship between trauma and osteochondrosis dissecans in coxa plana

To a certain extent this observation also lends support to NAGURA s (1937) theory that the cause of coxa plana is a compression fracture in the chondroepiphysis

In this connexion it may also be mentioned that KIRSCH (1961) described a case of coxa plana which initially exhibited the kind of picture typical of osteochondrosis dissecans

Regarding the frequency of subluxation in association with coxa plana there are few data in the literature SUNDT (1949) observed subluxation in 104 out of 153 and PERTTILA (1954) in 17 out of 33 finally healed cases EVANS (1958) detected subluxation in 42 out of 58 coxa plana hips He pointed out that the subluxation was very slight in the patients with good and fair end results

In the present series subluxation was noted in 45 hips out of 326 (13 8 per cent) Thirty of these were untreated and poorly healed while in 15 hips the result of treatment was poor

That coxa plana predisposes to secondary arthrosis has been emphasized by several authors *e g* MOLLER (1926) EYRE BROOK (1936) and SUNDT (1949)

In the present series secondary arthrosis was observed in 20 cases 17 of which were neglected These patients sought medical aid on account of symptoms in the hip due to the complicating arthrosis In 3 instances arthrosis developed in poorly healed cases during the time of observa tion

OBSERVATIONS WITH A BEARING ON AETIOLOGICAL FACTORS

Trauma

In 10 cases (3 6 per cent) of the present series the disease was preceded by a single trauma which may be considered directly related to the develop ment of coxa plana

Case 22 A girl aged 3 had fallen from the second floor and injured the hip region

Case 24 A girl aged 6 had had a traumatic luxation of the hip

Case 43 A boy aged 11 had been run over by a sledge resulting in con tusion and immediate pain in his hip

Case 74 A boy aged 7 had fallen from a tree and bruised the hip region

Case 141 A boy aged 6 had fallen from a pile of wood resulting in con tusion and immediate pain in his hip

Case 148 A boy aged 6 had bruised the hip Ecchymoses of the hip region resulted

Case 176 A boy aged 8 had fallen from a bar during gymnastics resulting in immediate severe pain in his hip

Case 191 A girl aged 9 had bruised her hip and been hospitalized on this account

Case 196 A boy aged 8 had fallen from a rafter in a barn and experienced immediate pain in his hip

Case 216 A boy aged 8 had fallen from a moving merry go-round and bruised his hip There was immediate pain

Furthermore in 31 cases (11 2 per cent) a single trauma was mentioned *e g* a fall during play or when riding a bicycle or skiing jumping from a rail or a stair a kick by a playmate but these everyday incidents had often occurred long before any hip symptoms were noted and must be regarded with great reserve as possible aetiological factors

In addition the series contains 7 cases (2 5 per cent) in which repeated trauma or excessive straining of the hip at the time of onset of symptoms can be taken into consideration In 3 cases the child had jumped innumerable

times from a roof or a tree In 1 case the symptoms had been preceded by intensive training in ski jumping in 3 cases by energetic training in bicycle riding

Infection

An infectious aetiology seems tenable in the following of the present cases

Case 102 A boy aged 5 started limping and complained of pain in the left knee in association with acute tonsillitis On radiological examination nothing noteworthy was observed in the knee About four months later coxa plana in an early stage of fragmentation was observed in the left hip

Case 54 A boy aged 11 fell ill with fever and hip pain Three months later contracture and limitation of movement in the right hip was observed at our Hospital A radiograph revealed marked condensation and moderate flattening of the right femoral epiphysis and a large step shaped defect in the ventral margin of the metaphysis Coxa plana in a late initial stage was diagnosed (Fig 4) The head socket distance was increased medially and slightly narrower than normal cranially The outline of the acetabulum was blurred The patient was fitted with Thomas splint At a follow up examination one year later the femoral epiphysis was in a stage of reconstruction The metaphyseal defect had been filled up to some extent but the head socket distance was still larger than normal medially The mobility of the hip



Fig 4 Case 54 boy aged 11 fell ill with fever and hip pain Three months later contracture and limitation of movement in the right hip Radiographs at this time *a* frontal — and *b* lateral view Marked condensation and moderate flattening of the femoral epiphysis and a large step shaped defect in the ventral margin of the metaphysis

showed some improvement The patient has failed to attend at suggested later follow up examinations

Case 149 A boy aged 3 years and 2 months developed symptoms in the left hip in connexion with acute appendicitis Appendicectomy was performed Three months later radiological examination revealed signs of epiphysiolysis of the proximal femoral epiphysis Typical coxa plana developed (Fig 5)

Case 161 A girl aged 7 was hospitalized for one month on account of burns Subsequently she showed a limp Three to four months later coxa plana on the left side was observed

Case 78 A boy aged 6 fell against a stump and sustained a wound in the right inguinal fold Wound infection developed and he was treated in bed for a month Subsequently he showed a persistent limp A radiological examination performed eight years later in our Hospital showed coxa plana on the right side in a late reparative stage

Hereditary and constitutional factors

Data regarding the possible occurrence of coxa plana in the patient s family was elicited in 172 of the present cases In 11 cases (6 4 per cent) radiologically verified coxa plana was recorded in members of the family

TABLE 22 — *Birth order in 153 cases of coxa plana and of all 585 children in the coxa plana families concerned*

Birth order	No of cases of coxa plana	No of children	Ratio
I	51	153	1 3 0
II	50	141	1 2 8
III	24	105	1 4 3
IV	5	62	1 12 4
V	8	42	1 5 3
VI	1	29	1 29 0
VII	9	23	1 2 6
VIII	3	15	1 5 0
IX	1	9	1 9 0
X	1	4	1 4 0
XI	—	1	—
XII	—	1	—
Total	153	585	

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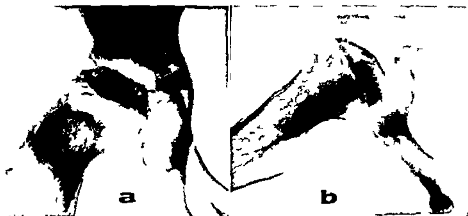


Fig 4 Case 54 boy aged 11 fell ill with fever and hip pain Three months later contracture and limitation of movement in the right hip Radiographs at this time *a* frontal — and *b* lateral view Marked condensation and moderate flattening of the femoral epiphysis and a large step shaped defect in the ventral margin of the metaphysis



Fig 5 Case 149 boy aged 3 years and 2 months developed symptoms in the left hip in connexion with acute appendicitis Appendicectomy was performed Three months later radiological examination revealed signs of epiphysiolysis of the proximal femoral epiphysis *a* frontal and *b* lateral view Later typical coxa plana with slight fragmentation of the epiphysis but without metaphyseal changes developed *c—d* Treated with Thomas splint End result good *e—f*

Birth order In 153 cases the birth order of the patient was recorded Table 22 shows the distribution of the cases by birth order groups and the relationship between these and the total number of children in the respective groups in the families concerned

Bone age Bone age was determined by GREULICH & PYLE s (1959) method on radiographs of the bones of the hand in 61 cases of coxa plana Some of these patients did not belong to the present series The cases were taken at

random and represented different stages of the disease Table 23 shows the differences between bone age and chronological age in the cases con cerned

Table 23 — *Skeletal age in 64 cases of coxa plana in different stages of the disease*

Stage	Delayed		Normal	Accelerated		Total no of cases
	No of cases	Months (range)	No of cases	No of cases	Months (range)	
Initial	6	19 (9—31)	—	—		6
Fragmentation	11	24 (12—48)	4	1	7	16
Reparative	11	19 (10—32)	12	1	13	24
Definitive (Growing period)	9	18 (6—30)	6	3	12 (9—13)	18
Total	37	19	22	5	11	64

Discussion

Trauma From the survey of the literature it appeared that many authors regard trauma as a possible cause of coxa plana

In the present series trauma was mentioned in 18 cases (17 3 per cent) but in the majority of these the statement has to be viewed with great reserve Parents usually look for a cause when their child starts limping or complains of pain in the hip Then the child itself or somebody in the family or its environment recalls a previous accident which is considered respon sible for the disease although it may be entirely insignificant

In regard to repeated minor traumata it is difficult to decide whether they are of aetiological significance in coxa plana It seems possible that they play a part as a contributory or precipitating cause

In 3 6 per cent of the present cases, however trauma appears to be a factor that significantly influenced the development of the disease

Infection As was already mentioned in the survey of the literature a number of authors have suggested that inflammatory processes may lead to coxa plana

The present series contains only a few cases in which an inflammatory aetiology can be suspected In case 54 it seems probable that coxa plana developed in connexion with acute synovitis of the hip joint

Case 149 (Fig 5) exhibited an obvious wedge shaped gap in the epiphyseal line ventrally This observation corroborates the view chiefly advanced by PONSETI & MCCLINTOCK (1956) that loss of cohesion of the cartilage matrix is the cause of the circulatory disturbance leading to necrosis of the epiphysis This loss of cohesion may be due to inflammation

Hereditary and constitutional factors Of the present patients 6 4 per cent had close relatives with radiologically verified coxa plana

HELBO calculated the incidence of coxa plana among the school children in Copenhagen as 0 44 pro mille MOSE (1964) reported frequencies of 0 08 pro mille among the population on Zealand and 0 09 pro mille in South Jutland If these figures are compared with the frequency of familial coxa plana observed in the present study i e 6 4 per cent it seems obvious that hereditary factors play a part in the development of the disease

One of the present patients who came from a family with 7 children had 3 siblings with coxa plana The lesion was unilateral in all four cases with typical radiological changes of the same type One of the four was a heterozygous twin whose twin sister was unaffected All the children were otherwise in good health and well developed The parents were healthy but 2 cousins (not brothers) of the father s have a limp due to shortening of one extremity

Birth order GOFF (1954) found that the first child most frequently develops coxa plana This observation was corroborated by PRIC (1962) Table 22 shows that in the present series too first and second children were most numerous among the patients with coxa plana But this is due to the fact that the absolute number of first and second children was largest in the families concerned These constituted about fifty per cent The ratios between the number of coxa plana children in the different birth order groups and the total number of children in these groups show that the morbidity was not higher among first and second children than among those born later The table shows the highest incidence in the group of seventh children i e 1 2 6 and the lowest – 1 29 – in the group of sixth children The wide variation is obviously due to the fact that the series analysed is too small The study seems however to indicate that the birth order is insignificant

Bone age In Table 23 it is seen that in the cases examined bone age and chronological age coincided in 22 In 37 cases the bone age was delayed by

random and represented different stages of the disease Table 23 shows the differences between bone age and chronological age in the cases concerned

TABLE 23 — *Skeletal age in 64 cases of coxa plana in different stages of the disease*

Stage	Delayed		Normal	Accelerated		Total no of cases
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In regard to repeated minor traumata it is difficult to decide whether they are of aetiological significance in coxa plana It seems possible that they play a part as a contributory or precipitating cause

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VI THE COURSE OF THE RADIOLOGICAL CHANGES IN COXA PLANA

JONSÄTER modified WALDENSTRÖM's (1923) classification of stages by uniting his last two groups (the growing period and the definitive stage) for the reason that the femoral head attains its final shape during the growing period. In this paper JONSÄTER's classification into initial stage, fragmentation stage, reparative stage and definitive stage is used.

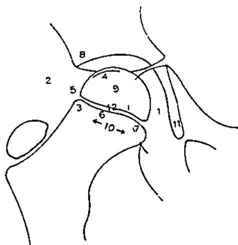


Fig 6 Early radiological signs in coxa plana. 1 *Increased head socket distance* WALDENSTRÖM's sign (1934). 2 Bulging of the joint capsule FERGUSON & HOWORTH (1934). 3 Rarefaction DREHMANN (1914) or rounding GAGE (1933) of the lateral margin of the metaphysis. 4 A strip shaped subcortical translucent area ventro-laterally in the epiphysis FREUND (1930). 5 Rarefactions in the lateral outline of the epiphysis close to the epiphyseal plate FREUND (1930). 6 Band shaped osteoporosis in the metaphysis close to the epiphyseal plate WALDENSTRÖM (1923). 7 Translucent area in the medial metaphyseal zone GILL (1910). 8 Changes in the roof of the acetabulum FROMME (1921). 9 The bony epiphysis smaller than in the unaffected hip, shape and structure of the epiphysis normal BERGMANN (1927). 10 Enlargement of the neck of the femur close to the epiphyseal plate FÈVRE & LAGRANGE (1936). 11 The tear shaped phenomenon: widening of Köhler's tear shaped figure HALKIER (1936). 12 Thickening of the epiphyseal plate HOWORTH (1939).



Fig 7 a—c

EARLY RADIOLOGICAL SIGNS

The importance of early diagnosis and early institution of treatment in coxa plana has been emphasized by the majority of authors The recognition of early radiological signs is therefore a point of major interest

Earlier observations

WALDENSTROM (1923) began his definition of the initial stage as follows »To begin with only limping without any change in the X ray picture»

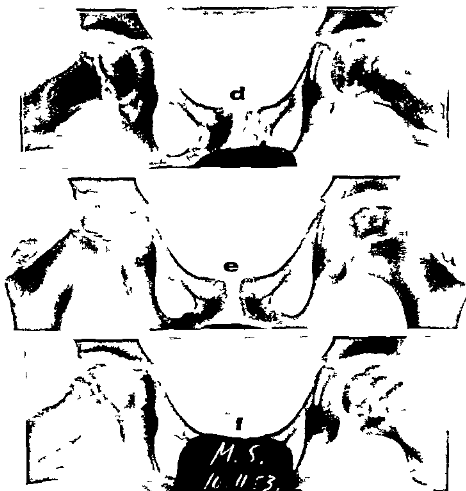


Fig 7 Case 141 boy aged 5 years and 10 months at onset Limping after fall from a pile of wood *a* and *b* 3 weeks after onset increased head socket distance slight swelling of the soft parts lateral to the left hip joint slight general osteoporosis of the hip region and thickening of the epiphyseal plate No structural changes of the epiphysis or changes of its outline Bed rest with extension for six weeks *c* and *d* 9 weeks after onset the radiological state was the same as before No clinical symptoms Weight bearing was allowed and *f* 2[illegible] weeks after onset a large translucent area in the ventral part of the epiphysis which was slightly flattened Treated with Thomas splint for 3 years After slight fragmentation and slight metaphyseal changes healing with spherical head

Many other authors have come to the conclusion that coxa plana begins with a prodromal stage during which no radiological changes or only changes of the soft parts are observable (FREUND 1930 FERGUSON &



Fig 7 a—c

EARLY RADIOLOGICAL SIGNS

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Case 141 (Fig 7) exhibited Waldenstrom s sign i e increased head socket distance slight swelling of the soft parts lateral to the left hip joint slight general osteoporosis of the hip region and thickening of the epiphyseal plate two months after onset No structural changes of the epiphysis or changes of its outline were discernible Later typical changes developed

Case 65 (Fig 8) Three months after onset the radiographs showed reduced height and breadth of the right bony epiphysis The calcium concentration outline and structure of the latter were completely normal The head-socket distance was the same as on the unaffected side Later this case showed moderate fragmentation and a good end result

Case 123 (Fig 9) A bilateral case At the first examination the left hip was evaluated as radiologically normal At a check up three months later the outline of the lateral pole of the epiphysis was irregular and exhibited a small defect This finding corresponds to the early sign described by FREUND (1930) Later typical changes developed

Case 124 (Fig 10) The only radiological sign was a small subcortical strip shaped translucent area proximally in the epiphysis Complete healing occurred without any other treatment than refraining from athletics and gymnastics for some weeks This case must be regarded as uncertain

The tear shaped phenomenon was observed in 25 cases of incipient coxa plana In 20 of these the phenomenon was obviously due to oblique projection caused by atrophy of the gluteal muscles on the affected side In 5 cases it could not be established whether the projection was oblique In a further 3 cases the tear shaped figure was narrower on the affected side than on the unaffected side

Discussion

Both previous reports and the present observations indicate that the early signs in coxa plana vary from case to case The radiological picture shown by case 141 (Fig 7 a) for instance is not pathognomonic of coxa plana it could just as well support a diagnosis of any kind of synovitis In uncertain cases it is of paramount importance to institute weight relief and keep the patient under observation for a sufficiently long time This has previously been emphasized by HOWORTH (1959) in particular

Most often the tear shaped phenomenon is probably due to oblique projection of the pelvis and this sign cannot be regarded as pathognomonic of coxa plana



Fig 8 Case 65 boy aged 7 at onset *a* and *b* 3 months after onset reduced height and breadth of the right epiphysis The calcium concentration outline and structure of the latter are completely normal The head socket distance is the same as on the unaffected left side Later this case showed moderate fragmentation and a good end result

HOWORTH 1934 HELBO 1953 NOVA MONTEIRO 1954 HOWORTH 1959 JACOBS 1960 RALSTON 1961)

Fig 6 demonstrates early radiological signs in coxa plana of the kind previously described in the literature

Observations on the present material

In the present series the radiological findings at the first examination were mostly typical and indisputable owing to the fact that the disease process was already advanced But in certain cases the first diagnosis was tentative Some of these may be described as examples of early signs

Case 141 (Fig 7) exhibited Waldenstrom's sign i e increased head socket distance slight swelling of the soft parts lateral to the left hip joint slight general osteoporosis of the hip region and thickening of the epiphyseal plate two months after onset No structural changes of the epiphysis or changes of its outline were discernible Later typical changes developed

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Both previous reports and the present observations indicate that the early signs in coxa plana vary from case to case The radiological picture shown by case 141 (Fig 7 a) for instance is not pathognomonic of coxa plana it could just as well support a diagnosis of any kind of synovitis In uncertain cases it is of paramount importance to institute weight relief and keep the patient under observation for a sufficiently long time This has previously been emphasized by HOWORTH (19[illegible]) in particular

Most often the tear shaped phenomenon is probably due to oblique projection of the pelvis and this sign cannot be regarded as pathognomonic of coxa plana



Fig 9 a–c

CHANGES IN THE CAPITAL EPIPHYSIS

Initial stage

Observations on the present material This stage was counted from the onset of symptoms to the time when the bony epiphysis exhibited the first signs of fragmentation

Duration of the initial stage In the present series 117 hips were studied in the initial stage i e 101 in unilateral and 16 in bilateral cases The dura

Fig 9 Case 123 boy aged 7 years and 5 months a
for five months before the first visit At th f
shows fragmentation In the lateral outline of t
tion which was overlooked Thomas splint on th
later *c* and *d* the rarefaction in the lateral p
metaphyseal changes on the right side After a f
of coxa plana on the left side with flattenin
6 months in bed Thomas splint on the left s
sides Osteochondrosis d

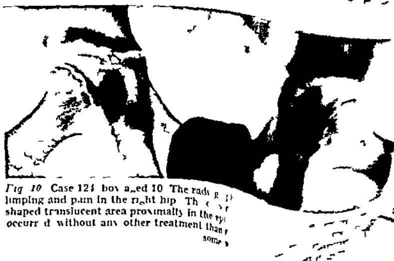


Fig 10 Case 124 boy aged 10 The radi
limping and pain in the right hip Th
shaped translucent area proximally in the ep
occurr d without any other treatment than
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ation was

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tion of the initial stage could be evaluated in 116 cases as shown in Table 24

Table 25 shows the relationship between the duration of the initial stage and the age at onset of the disease It is seen that *the duration of the initial stage was independent of the onset age*

TABLE 24 — *Duration of the initial stage in 116 cases*

Time in months	No of cases
under 6	57
6—12	59

Mean duration 5 6 months

TABLE 25 — *Relationship between duration of the initial stage and onset age in 116 cases*

Duration of initial stage in months	Onset age in years						
	2—3	4—5	6—7	8—9	10—11	12—14	No of cases
Under 6	4	17	26	7	2	1	57
6—12	5	19	22	7	6	—	59

The radiological changes occurring during this stage in the epiphysis consisted of depressions and breaks in the outline as a rule in its proximo-ventral portion translucent areas often subcortical and flattening and condensation These changes occurred almost invariably except in mild abortive cases in which condensation was mostly absent

The changes varied in degree from case to case and it goes without saying that variations were seen in one and the same case depending on how far the process had advanced

The strip shaped subcortical translucent area mentioned in connexion with early signs (p 57) was a relatively frequent sign in the initial stage It was transitory owing to the fact that the cortical lamella was resorbed in more advanced cases or pressed against the spongy bone A subcortical strip of this kind shown in Fig 11 (case 32) was observed in 43 cases This radiograph was taken five weeks after the onset of symptoms



Fig. 11. Case 32, boy aged 9. Five weeks after onset. Marked subcortical strip-shaped translucent area in the lateral view (*b*).

Condensation of the epiphysis often occurred early in the initial stage. In exceptional cases it was observable immediately before or in connexion with fragmentation. Case 141 (Fig. 7) is an example of absent condensation.

The height of the chondroepiphysis remained unaltered during the initial stage. This was shown by the fact that the distance from the epiphyseal cartilage to the socket of the acetabulum on the lateral view was the same as on the unaffected side. In some cases with a »vacuum phenomenon« on the radiographs, the height of the chondroepiphysis could be measured directly on the pictures.

Discussion of the initial stage. The duration of the initial stage was indicated by WALDENSTRÖM as a half to one year. HELBO reported a mean duration of 12 months in his series, the variation being 5 to 18 months.

BERGSTRAND (1961) observed subcortical fissures or changes of the outline in the proximal portion of the femoral epiphysis in all cases of his series. These changes were demonstrable until eight months after the onset of symptoms.

The condensation observable in the epiphysis has been discussed by many authors. AMSTAD (1916), CAAN (1924) and others ascribed it to sclerosis associated with increased deposition of calcium. WIDEROE (1921) and LEHMANN (1940) regarded the condensation as a direct necrotic manifestation analogous to the sequestrum in osteomyelitis.

AXHAUSEN & BERGMANN (1937) concluded that the condensation was due to compression of necrotic spongy bone.

JONSÄTER (1953), who investigated this point histologically, stated that a compression of the trabeculae obviously takes place, but he did not think

that this phenomenon accounts for the marked condensation seen in early cases in which the epiphysis has still maintained its original shape

BERNBECK (1954) attributed the early condensation to an increase in inorganic substance due to penetration of chondroitinsulphuric acid from the surrounding cartilaginous tissue (»Kalk Phanerose») The condensation seen in later stages he ascribed to compression of necrotic spongy bone

Case 43 Fig 12 in the present series is an example of intensive homogeneous condensation involving the whole of the epiphysis which showed very slight flattening In this case it is difficult to explain the condensation as due entirely to compression It seems more probable that it was a result of total necrosis with markedly increased calcium concentration (ivory epiphysis) A LANGENSKIOLD (1952) described a case of tuberculous spondylitis in which the first radiological examination showed an ivory vertebra *without any loss of substance or signs of compression*

BERGSTRAND (1961) found that the breadth of the bony epiphysis in the initial stage was smaller on the affected side and that the epiphyseal breadth



Fig 1 Case 43 boy aged 11 years and 3 months at onset *a* and *b* 5 months after an obvious single trauma Pronounced condensation without any appreciable flattening of the epiphysis Widening of the head socket distance

of the unaffected hip was fairly constantly attained and exceeded six to nine months after onset. In the present study this point was not checked by systematic measurements but in many cases BERGSTRAND's finding could be confirmed as is shown in Fig. 8. The phenomenon is attributable to inhibited growth of the necrotic ossific centre (PONSETI & COTTON 1961).

The shape and size of the chondroepiphysis was studied arthrographically by JONSÄTER (1953) and GOFF (1954) by measurement of the epiphyseal plate socket distance on radiographs by BERGSTRAND (1961) and in connexion with arthrotomy by HERZOG (1961). These investigations showed that the chondroepiphysis maintained its normal height throughout the initial stage and for part of the fragmentation stage.

Fragmentation stage

In this study the fragmentation stage was counted from the time when the first radiological signs of fragmentation of the epiphysis were discernible until the time when the first signs of reconstruction could be seen on the radiographs.

Observations on the present material. On the basis of serial radiographs the *duration of the fragmentation stage* could be evaluated in 113 of the present cases as is seen in Table 26. The mean duration was 10.8 months.

TABLE 26. — *Duration of the fragmentation stage in 113 cases*

Time in months	No. of cases
Under 6	27
6—12	52
12—24	34

Mean duration 10.8 months

TABLE 27. — *Relationship between duration of the fragmentation stage and onset age in 113 cases*

Duration of fragmentation stage in months	Onset age in years												Total no. of cases
	2—3		4—5		6—7		8—9		10—11		12—14		
	No. of cases	%	No. of cases	%	No. of cases	%	No. of cases	%	No. of cases	%	No. of cases	%	
Under 6	2	20	7	19	8	19	7	50	3	37.5	—		27
6—12	6	60	16	43	23	53	3	21	3	37.5	1	100	52
12—24	2	20	14	38	12	28	4	29	2	25	—		34

The relationship between the duration of the fragmentation stage and the age at onset of the disease appears in Table 27 A lower onset age does not seem to shorten the duration of the fragmentation stage which was 6 to 12 months in the majority of the cases with an onset age of 2 to 7 years Among those who were 8 to 11 years old at the time of onset of the disease the majority had a fragmentation stage of under 6 months but the number of cases is too small to allow of any definite conclusions Fragmentation was found to begin in the ventrolateral portion of the epiphysis and is best seen on the lateral view The structure of the epiphysis which usually showed condensation became irregular less dense areas occurred and the epiphysis became fragmented Fragmentation was often preceded by flattening of the bony nucleus and as fragmentation progressed the flattening was further increased

The degrees of fragmentation showed wide variations In some cases the epiphysis was divided into only two or three pieces while in others the osseous centre seemed to be completely fragmented In extreme cases only a few dense fragments were seen or a thin condensed lamella proximal to the metaphyseal surface

Discussion of the fragmentation stage Waldenström indicated the duration of the fragmentation stage as two to three years In Stahl s series the duration from onset of the disease to the beginning of the reparative stage was an average of 16 months with a variation of 7 to 31 months Helbo noted a mean duration of 26 months from the onset to the beginning of reconstruction in untreated and »symptomatically» treated patients and 16 months in those treated by protracted bed rest Bergstrand observed maximal fragmentation from 9 to 23 months after onset

Even in the first reports on coxa plana fragmentation of the femoral epiphysis was described Waldenström (1909) Perthes (1910) Schwarz (1914) and others regarded the fragmentation as a sign of a destructive process By contrast Calvé (1910) believed that the epiphysis had not been uniform but primarily separated into two or more small bony nuclei scattered over the chondroepiphysis He stated that a total absence of any osseous or cartilaginous destructive process was a feature typical of the disease

In contrast to current views Freund (1930) maintained that the fragmentation stage instead of being a destructive phase is a stage of intensive reorganization originating from the surrounding normal tissues This was confirmed by Jonsäter s (1953) histological investigations

As mentioned above the degree of fragmentation shows wide variations For this reason O Garra (1959) divided his series into two groups »anterior

Perthes disease» and »involvement of the whole epiphysis» In a series of coxa plana patients GOFF (1959) distinguished between a type with total epiphyseal involvement (37 per cent) and another type with partial epiphyseal involvement (50 per cent) The remaining patients (13 per cent) had bilateral lesions

RALSTON (1959) calculated the maximal percentage of epiphyseal involvement and studied the relationship between this parameter and various others The best correlation was noted between the extent of necrosis and the duration of the disease the larger the proportion of the epiphysis showing fragmentation the longer the duration Furthermore the investigation revealed that the smaller the portion of the epiphysis involved the more anatomical was the end result

Owing to the wide variation of the radiological changes it is very difficult to make any accurate classification of a large series on the basis of the extent of the necrosis *There are of course a number of typical and obvious cases* in which evaluation is easy but very often no indisputable information regarding the extent of the necrosis is obtainable from the radiographs alone JONSATER's (1953) histological investigations suggest that the necrosis is total broadly speaking

Reparative stage

In the present study radiological reparative stage is used to denominate the period from the appearance of the first signs of reossification of the fragmented epiphyseal bony nucleus until the time when the latter is uniform its structure is normalized and the epiphysis has attained its final shape

Observations on the present material In the present series the duration of the reparative stage could be evaluated in 81 cases as is shown in Table 28

TABLE 28 — *Duration of the reparative stage in 81 cases*

Duration in months	No of cases
12—24	20
24—36	27
36—48	34

Mean duration 3[illegible] months

TABLE 29 — *Relationship between duration of the reparative stage and onset age in 81 cases*

Duration of reparative stage in months	Onset age in years												Total no of cases
	2—3		4—5		6—7		8—9		10—11		12—14		
	No of cases		No of cases	%	No of cases	%	No of cases	%	No of cases	%	No of cases	%	
12—24	1	14 3	7	25 0	8	28 5	4	28 5	—		—		20
24—36	4	57 0	9	32 0	8	28 5	4	28 5	2	75 0	—		27
36—48	2	28 7	12	43 0	12	43 0	6	43 0	1	25 0	1	100 0	34

The mean duration was 32 months Table 29 demonstrates the relationship between the duration of this stage and the age at onset of the disease It is seen that almost two thirds of the cases in the lowest age group had a duration of under 36 months while almost one half in the older groups had a duration of over 36 months None of the patients who were 10 to 14 years old at the time of onset had a duration of under 24 months The different groups are too small however to allow of any definite conclusions

As a rule the first signs of reossification were seen in those areas where fragmentation began *i e* in the ventrolateral portion of the epiphyseal bony nucleus At this time resorption of necrotic bone tissue still occurred in other areas of the epiphysis The radiographs showed both point shaped new ossific centres in entirely demineralized areas and reconstruction of bone in the marginal areas of remaining bone fragments in which resorption had come to a standstill and regeneration had begun Occasionally diffuse homogeneous condensation was seen in entirely demineralized areas probably representing osteoid tissue which gradually undergoes mineralization Later the newformed bone substance in previously entirely decalcified areas fused with the remaining reossified fragments with the result that the ossific centre became uniform and the defects in its outline were made good As a rule the proximoventral portion of the epiphysis was ossified last An increase in breadth of the epiphysis ran parallel with its reossification

Signs of early reconstruction In 22 of the present cases radiographs taken late in the initial stage showed an osseous shadow in the chondro epiphysis lateral to the bony nucleus The primary ossific centre was still uniform although at its lateral margin the structure exhibited some rarefaction as a sign of incipient demineralization As judged from the radio graphs the above mentioned bone formation could not consist of a fragment detached from the uniform ossific centre The further radiological develop

ment clearly showed that the reformation of bone described here consisted of a fresh ossification area in the lateral portion of the chondroepiphysis the first visible sign of the formation of new bone preceding fragmentation in the bony epiphysis proper Fig 13 (case 128) illustrates this phenomenon As far as I know this early reossification phenomenon has not previously been described in the literature

Discussion of the reparative stage WALDENSTROM (1923) indicated the duration of the reparative stage as one or two years According to BRAILSFORD (1918) healing is completed during or after the fourth year counted from the onset In HELBO s (1953) series the mean duration from onset to primary healing was 52 months in untreated patients and 42 months in cases treated by protracted bed rest

In mild abortive cases reparation of the femoral epiphysis is complete Occasionally an epiphysis which has undergone slight fragmentation is rebuilt so as to become entirely symmetrical with the unaffected side The present series contained only a few such cases BRAILSFORD (1948) HELBO

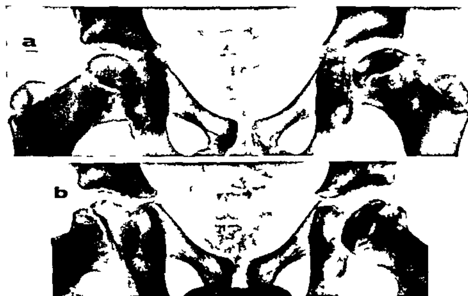


Fig 13 Case 128 boy aged 6 at onset Limping for three months before the first examination *a* frontal and *b* lateral view Coxa plana on the left side initial stage with moderate flattening and condensation of the epiphysis A broad band shaped translucent area across the metaphysis in the frontal view A large furrow shaped defect in the proximal surface of the metaphysis close to the ventral margin in the lateral view Note the large ossification area laterally in the chondroepiphysis before the bony epiphysis shows fragmentation

(1953) GOFF (1954) and others have described complete radiological healing

In the majority of cases with good end results a slight reduction in height and increase in breadth of the epiphysis occur In most cases of coxa plana broadening of the epiphysis is one of the most typical features For this reason BERGSTRAND & NORMAN (1961) suggested that the denomination coxa plana should be replaced by coxa lata

Definitive stage

When the bony epiphysis has become uniform the defects in its outline have been filled out and its structure has been normalized the process is primarily healed and has reached its definitive stage but the femoral head *still increases in size throughout the normal growing period How much the*



Fig 14 Case 229 boy aged 6 years and 6 months at onset The radiographs *a*—*d* show the development of osteochondrosis dissecans

head will grow during the definitive stage depends of course on the age at which this stage is attained

The final shape of the head shows wide variations depending on the course of the disease process The range of this variation is best illustrated by the large number of different denominations by which different authors have described the ultimate shape spherical ball formed ovoid or oval elliptical mushroom shaped cylindrical quadrangular or pyramid shaped

In the present series *the mean duration of the process of the disease was four years and four months as counted from the onset of the illness until primary healing had taken place*

In some cases the result of the reparative process was not a uniform head but one where one or more loose fragments remained in the proximal portion of the epiphysis (Fig 14)

CHANGES IN THE METAPHYSIS AND THE EPIPHYSEAL PLATE

Earlier investigations

Radiological changes In his first paper on coxa plana LEGG described radiological changes in the metaphysis which he interpreted as necrotic

Osteoporosis revealed by focal or band shaped translucent areas in an early stage of the disease have been described by WALDENSTROM (1910 1923) PERTHES (1913) SCHWARZ (1914) DREHMANN (1914) GAGE (1933) GILL (1940) WIRZ (1953) GOFF (1954) CAFFEY (1951) and others

GILL maintained that the metaphysis is the primary site of the process the necrosis of the epiphysis being secondary

BERGSTRAND (1961) described a local marginal decalcifying process («Usurierung») in the proximal surface of the metaphysis preceding fragmentation of the epiphysis This change he interpreted as the first visible sign of granulation tissue invading the epiphyseal bony nucleus

MINDELL & SHERMAN (1951) were able to follow the metaphyseal changes in 53 cases The usual change consisted of a diffuse irregular zone of decreased density which sometimes appeared early and sometimes late This defect was filled in as the head of the femur healed From their observations the authors concluded that extensive changes in the femoral neck generally indicate a poor prognosis They found that the metaphyseal changes led to *asymmetrical and retarded growth or epiphyseal arrest*

Changes resembling those described by MINDELL & SHERMAN were also reported by GOFF (1951)

spicuous there Occasionally this defect was circular and involved the whole periphery of the metaphyseal surface In such cases the central portion of the latter formed a plateau shaped elevation surrounded by depressions An extreme example of this is shown in Fig 15 (case 14)

During the further course the cases exhibiting a furrow shaped depression in the metaphyseal surface showed a defect of the metaphyseal margin

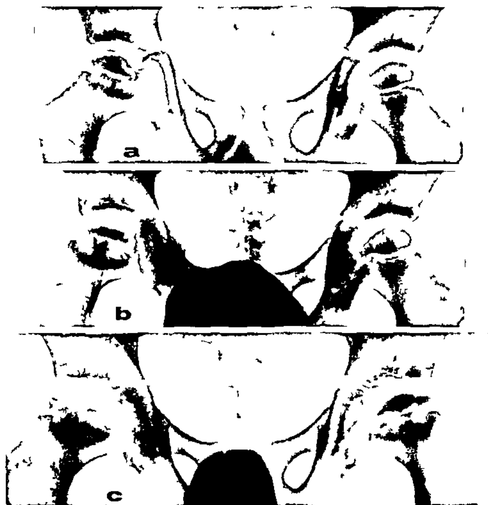


Fig 1 Case 11 boy aged 4 at onset The radiographs demonstrate severe symmetrical metaphyseal changes with circular defects in the periphery of the proximal metaphyseal surfaces and plateau shaped elevations in the central portions of the latter Total necrosis of the epiphysis *a* 6 months after onset *b* 10 months after onset *c* 23 months after onset Treated at first with Thomas splint on the right side then by bed rest for one and a half year and finally with Thomas splint on the left side End result elliptical head on both sides

leading to the development of a gap in the ventral portion of the epiphyseal plate The picture resembled that seen in the group of cases primarily exhibiting a gap (It is possible that the development of a gap in this group had been preceded by a stage in which a furrow shaped depression in the proximal metaphyseal plane occurred) During the fragmentation stage the defect in the metaphyseal margin was enlarged and gradually developed into an oblique or most often a step-shaped defect (Fig 1) The cause of this seemed to be that ossification in the central portion of the metaphysis continued while the growth in the area of the defect was arrested The margins of the step shaped defect were gradually rounded off and at the same time the whole outline of the metaphyseal surface became irregular During the later course the metaphyseal surface invariably developed a proximally directed convexity

During the reparative stage the metaphyseal defect was made good in the majority of cases in such a way that the bony epiphysis grew in the distal direction towards the defect which was thus filled out by the epiphysis Frequently isolated ossific centres were seen within the metaphyseal defect Gradually these fused with the ingrowing epiphysis As a natural result of this series of events the epiphyseal line assumed a more or less marked step-shaped irregularity in its ventro-lateral part (Fig 21)

In 3 of the cases with severe metaphyseal changes the metaphyseal defect disappeared owing to reformation of bone at its margins so that the metaphyseal surface was levelled and the epiphyseal line became regular although with a proximally directed convexity (Fig 16 case 46)

Even in areas which on the radiograph did not show any metaphyseal defect proper a tendency of the epiphysis to grow out over the metaphyseal margin was discernible with broadening of the epiphysis resulting This increase in breadth was often most conspicuous in the lateral portion in which an outgrowth of the epiphysis extending far over the femoral neck even to the greater trochanter could be seen This observation seems to indicate that there were metaphyseal changes also in other parts of the metaphyseal margin although these were not visible on the radiographs

In parallel with the ossification of the metaphyseal defect *an increase in breadth of the metaphysis occurred* Periosteal apposition of bone was a relatively frequent finding at the borderline between the metaphysis and the femoral neck usually cranially to the latter

Towards the end of the reparative stage typical deformations in the meta-epiphyseal borderline area occurred

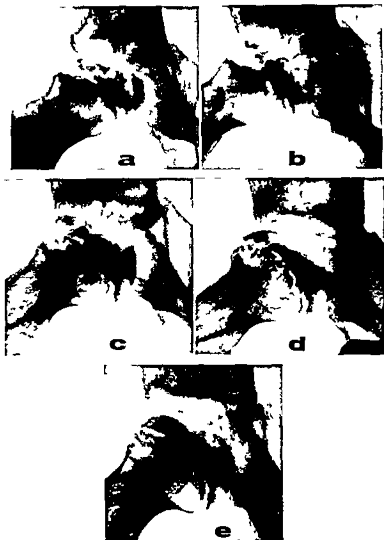


Fig 16 a—e

Normally the distal surface of the femoral epiphysis and the proximal surface of the metaphysis are almost straight Between these the epiphyseal plate is situated appearing on the radiographs like a line or a band shaped space between the epiphysis and the metaphysis

In the great majority of cases in the present series various degrees of irregularity of the proximal surface of the metaphysis were observable

As has already been mentioned the metaphyseal surface was convex in the proximal direction The convexity sometimes had a smooth outline and

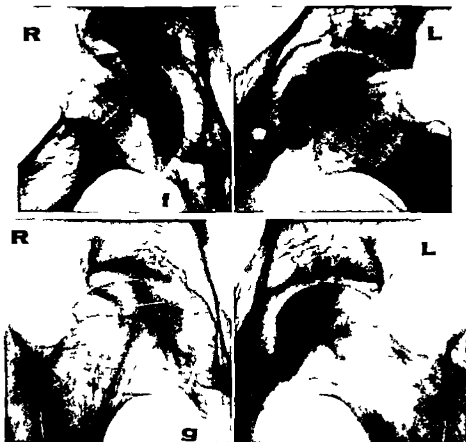


Fig 16 Case 46 boy aged 6 years and 10 months at onset A large oblique metaphyseal defect seen in *a* and *b* disappeared owing to reformation of bone at its margins as seen in *c*—*e* The epiphyseal line became regular The radiographs *a*—*e* were taken from 10 to 34 months after onset at intervals of 4 to 12 months *f* and *g* about 10 years after onset Treatment Thomas splint for 2 years and 9 months End result good

sometimes showed a more or less regular undulation or the contour was entirely irregular with deep distally directed depressions and proximally directed plateau shaped or step-shaped elevations The depressions were situated peripherally and corresponded to the primary marginal defects while the elevations were more centrally located

Often the routine radiographs did not provide an accurate concept of the changes described here Tomograms were very informative and on these the grave deformation of the metaphyseal surface was often striking (Fig 17 case 262)



Fig 17 a—c

The remodelling process in the metaphysis took place in parallel with the reparative process in the epiphysis On inspection of the large number of radiographs on which this study is based it was clearly seen that the two processes were dependent on each other but it was impossible to distinguish between cause and effect In cases where fragmentation had been slight or a coherent layer of spongy bone developed relatively soon upon the metaphyseal surface the deformation of the metaphysis was slighter Relatively marked irregularity of the metaphyseal surface was usually associated with a high degree of fragmentation and slow consolidation of the epiphysis In many cases the radiographs conveyed the impression that

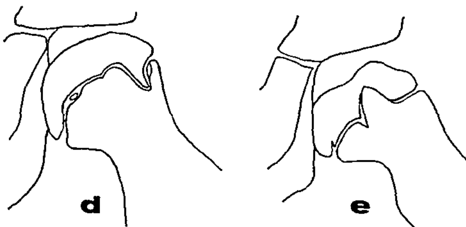


Fig 17 Case 262 boy aged 6 years at onset *a* routine radiograph *b* and *c* tomograms with a 1 cm level distance 5 years after onset Late reparative stage *d* and *e* drawings to *b* and *c* Routine radiographs do not provide an accurate idea of the changes in the meta epiphyseal borderline Tomograms give very good information regarding irregularities in the metaphyseal surface

the elevated central portion of the metaphysis intervened with the fusion of the ossifying epiphyseal fragments which was slow in this site In some cases months and years elapsed before fusion of the epiphysis occurred in this area and as a rule the layer of bone remained very thin and it seldom exhibited a normal structure (Fig 18)

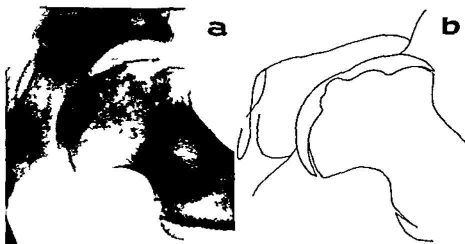


Fig 18 Case 212 boy aged 8 at onset *a* 11 years after onset *b* drawing to *a* The subcapital epiphyseal line is partially closed The metaphyseal surface is very irregular with a central elevation In the proximal part of the epiphysis the layer of bone tissue is thin and the bone structure is still irregular Untreated case



Fig 17 a—c

The remodelling process in the metaphysis took place in parallel with the reparative process in the epiphysis On inspection of the large number of radiographs on which this study is based it was clearly seen that the two processes were dependent on each other but it was impossible to distinguish between cause and effect In cases where fragmentation had been slight or a coherent layer of spongy bone developed relatively soon upon the metaphyseal surface the deformation of the metaphysis was slighter Relatively marked irregularity of the metaphyseal surface was usually associated with a high degree of fragmentation and slow consolidation of the epiphysis In many cases the radiographs conveyed the impression that



Fig 0 Examples of asymmetrical growth owing to premature fusion of the epiphyseal line a valgus position of the femoral head after fusion of the lateral part of the epiphyseal line b varus position of the head as a result of premature fusion in the medial part of the epiphyseal line c increased antetorsion of the head owing to fusion of the anterior part of the epiphyseal line

this case closed earlier on the ventral side (Fig 20 c) Retrotorsion was not seen in any cases

In order to enable evaluation of the relationship between premature closure of the subcapital epiphyseal line and the final shape of the femoral head the present ultimately healed cases of unilateral coxa plana were

divided into two groups depending on whether the serial radiographs revealed premature or normal closure of the epiphyseal line

In this paper premature closure stands for fusion that had certainly taken place at least one year earlier on the affected side than on the unaffected side Normal closure means that fusion occurred less than a year earlier on the affected side

The group with premature closure comprises 12 cases the group with normal closure 20 cases (Both groups were certainly larger but owing to long intervals between the examinations radiological evidence is lacking)

Table 30 shows the relationship between fusion of the epiphyseal line and the ultimate shape of the femoral head It appears in the table that in more than half the cases premature closure of the subcapital epiphyseal line was associated with poor healing of the femoral head In the group with normal closure the 2 cases which did not heal with a spherical femoral head developed a condition resembling osteochondrosis dissecans

TABLE 30 — *Relationship between closure of the subcapital epiphyseal line and ultimate shape of the femoral head*

Closure of the epiphyseal line	Shape of the femoral head			Total
	Spherical No of cases	Elliptical No of cases	Irregular No of cases	
Normal	18	—	2	20
Premature	5	13	4	42

From the standpoint of the end result in the femoral head premature closure of the epiphyseal line thus seems to be an unfavourable sign

For the sake of evaluating the relationship between the metaphyseal changes and the closure of the subcapital epiphyseal line the ultimately healed cases were classified according to the degree of metaphyseal changes The classification was made at a late reparative stage as close as possible to the time of epiphyseal fusion The following principles of classification were used

Small or no changes the proximal surface of the metaphysis plane or regularly convex

Moderate changes step shaped marginal metaphyseal defect filled up by the epiphysis otherwise a regularly convex metaphyseal surface

Marked changes metaphyseal surface very irregular the central portion plateau shaped and elevated

The increase in breadth of the metaphysis as compared with the unaffected side was measured in the lateral view while the shortening of the femoral neck was measured in the frontal view

The relevant observations are listed in Table 31 which shows that premature closure of the epiphyseal line in most cases was associated with marked metaphyseal changes In cases with normal closure the metaphyseal changes as a rule were slight The increase in breadth of the metaphysis and the decrease in length of the femoral neck were clearly larger in the cases showing premature closure than in those showing normal closure

TABLE 31 — *Degree of metaphyseal changes broadening of the metaphysis and shortening of the femoral neck in 4[illegible] unilateral ultimately healed cases with premature closure and 0 cases with normal closure of the subcapital epiphyseal line*

Closure of the epiphyseal line	Degree of metaphyseal changes			Broadening of the metaphysis in mm mean (range)	Shortening of the femoral neck in mm mean (range)
	Slight No of cases	Moderate No of cases	Severe No of cases		
Premature	3	5	34	12 (3—23)	1[illegible] (0—30)
Normal	16	4	—	4 3 (0—9)	4 5 (0—9)

It may be concluded that marked metaphyseal changes and marked broadening of the metaphysis and retardation of the longitudinal growth of the femoral neck are unfavourable prognostic signs indicating that the epiphysis will close prematurely

Fig 21 (case 218) shows the radiological course in a girl who was 7 years old at the onset of coxa plana This case represents moderate metaphyseal changes

Discussion

The present observations concerning the *metaphyseal changes and premature closure of the subcapital epiphyseal line* agree well with the above mentioned reports of MINDELL & SHERMAN GOFF and EVANS With regard to the ossification of the metaphyseal defect there is a high degree of correspondence between the observations made in the present series and those of MOSE

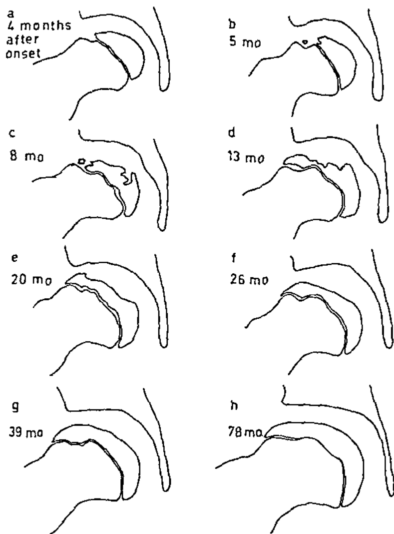


Fig 1 Drawing based on lateral radiographs of the right hip showing the radiological course of coxa plana in a girl aged 7 years at onset of the disease (case 248) *a* 4 months after onset the epiphysis is slightly flattened in the ventral margin of the metaphysis there is an oblique defect *b* 5 months after onset fragmentation in the ventral part of the epiphysis a step shaped defect in the ventral margin of the metaphysis there is a small ossification centre in the metaphyseal defect *c* 8 months after onset fragmentation proximally in the epiphysis the ventral part of the epiphysis is growing into the metaphyseal defect the margins of the defect are rounded the ossification centre in the defect is enlarged thickening of the periosteum ventrally on the neck *d* increased demineralization proximally in the epiphysis the ossification centre in the metaphyseal defect is fused with the ventral part of the epiphysis which fills up the defect the metaphysis is broadened *e—g* mineralization of the epiphysis proceeding the borderline of the metaphyseal defect is still visible the epiphyseal line is slightly wave like *h* 78 months after onset the central part of the epiphyseal line is closed

The premature fusion of the subcapital epiphyseal line may begin in different areas of the growth zone This accounts for the deviations from the normal relationship between the positions of the femoral head and neck seen in coxa plana and it also explains the conflicting conclusions drawn by certain previous authors regarding the final deformation in this disease Thus LEVY (1911) for instance described cases in which the femoral head occupied a varus position in relation to the neck and suggested that the name of the condition osteoarthritis deformans coxae juvenilis should be substituted by »coxa vara capitalis» DREHMANN (1914) on the other hand reported cases with a valgus position of the femoral head in relation to the neck and suggested the denomination »coxa valga epiphysaria»

Analogous deformities following partial epiphyseal closure are known from other skeletal diseases In tibia vara for instance premature closure of the medial portion of the proximal epiphyseal line of the tibia is a common phenomenon and leads to a marked increase of the varus deformity (A LANGENSKIOLD 1952)

The degree of the deformity under discussion is of course entirely dependent on how long the growth continues and how rapid it is in still functional parts of the growth zone after partial fusion of the epiphyseal line has taken place

Thickening of the metaphysis The cause of the increase in breadth of the metaphysis has been discussed by many authors BERNBECK (1954) regarded this broadening in part as initial apposition of osseous lamellae caused by the irritation resulting from overgrowth of the epiphysis over the metaphyseal border in part as appositional increase in thickness implying strengthening of weak osseous parts

HELBO (1954) who — like many other authors — observed periosteal apposition in the lateral surface of the femoral neck accorded no major significance to this phenomenon from the standpoint of the thickening of the femoral neck He observed the same periosteal reaction in an early stage in patients who later exhibited good end results without any thickening of the neck of the femur HELBO regarded the metaphyseal changes and weight-bearing as responsible for the increase in breadth

In the present series there are cases in which periosteal apposition undoubtedly seemed to contribute to the increase in breadth of the femoral neck but in the great majority of cases no such reaction of the periosteum was observable As evaluated on the basis of the radiographs the thickening of the femoral neck was obviously due to growth phenomena in the metaphysis which is the region where the increase in breadth appears first and is most conspicuous

An increase in volume of the proximal end of the femur is relatively frequent after reduction of congenital luxation of the hip, and also occurs in cases where no radiological signs of epiphyseal necrosis are observable Such a coxa magna is attributed to local growth stimulating phenomena possibly elicited by the reposition trauma

It seems probable that similar stimulating factors also play a part in coxa plana

Formation of a step in the metaphysis A LANGENSKIOLD (1952) described the radiological changes in the infantile type of tibia vara (osteochondrosis deformans tibiae) Some cases exhibited a defect in the proximal metaphysis of the tibia causing a definite step The defect was attributed to growth arrest in one portion of the metaphysis and continued ossification in the remainder The step shaped defect was filled out by a broadened part of the epiphyseal cartilage and in a later stage it was found to be occupied by the bony epiphysis (Fig 22)

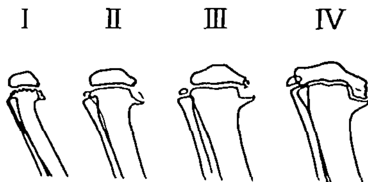


Fig Formation of a step shaped metaphyseal defect in tibia vara Compensatory epiphyseal growth the defect is occupied by the bony epiphysis (According to A LANGENSKIOLD 1952)

By mechanical injury to the proximal tibial growth cartilage in rabbits A LANGENSKIOLD (1955) provoked changes resembling those seen in tibia vara *i e* a metaphyseal depression compensatory growth of the epiphysis and a varus deformity (Fig 23)

Metaphyseal defects associated with osteomyelitis and tuberculosis in children are relatively frequent A LANGENSKIOLD (1955) has described compensatory epiphyseal filling of these defects and emphasized the resemblance between this regenerative process and that observed by him in tibia vara (Fig 24)

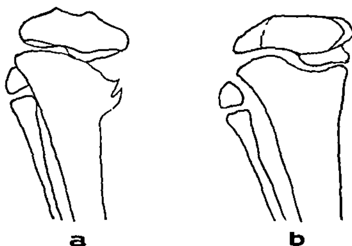


Fig 23 a drawing of a radiograph of the tibia of a young rabbit taken 10 days after removal of the medial part of the zone of cartilage cell columns from the proximal epiphyseal plate There is an oblique defect in the metaphysis *b* drawing of a radiograph of the upper end of the tibia of a rabbit taken 16 days after removal of the medial part of the zone of cartilage cell columns from the epiphyseal plate The metaphyseal defect is occupied by an extension of the bony epiphysis (According to A LANGENSKIOLD 1954)



Fig 24 A tomogram of a patient aged 7 years and 3 months The steplike deformity had developed in the distal growth zone of the femur after osteomyelitis in infancy Compare with *Fig 27 b* The resemblance of the changes is striking (Reproduced by courtesy of LANGENSKIOLD & RISKA and the *J Bone & Joint Surg* Am 1964)

VIII. THE GREATER TROCHANTER

Earlier observations

In his paper of 1913 PERTHES pointed out that the greater trochanter was strikingly large in some of his cases. Similar observations were reported by AXHAUSEN (1923). These authors attributed the hypertrophy to proliferative phenomena around the greater trochanter. BIBERGEIL (1912), who also noted that the trochanter was large, correlated this finding with atrophy of the femoral head and neck.

SUNDT (1920) described in his monograph some cases of coxa plana with hypertrophy of the greater trochanter. Since in some of these the trochanter was also hypertrophic on the unaffected side, he drew the conclusion that the hypertrophy had no connexion with the disease process in coxa plana.

In his paper called »The definite form of the Coxa plana» WALDENSTRÖM (1922) described the radiological picture in his end result group 3 as follows: »The upper pole of the caput is edgeformed and usually lower than the summit of the greater trochanter», but he offered no explanation of this observation.

CAAN (1924) also discussed this phenomenon without being able to trace its cause.

PERTTILÄ (1954) reported that in 10 out of 33 patients with coxa plana who were followed up, the tip of the greater trochanter was situated more cranially than the proximal pole of the femoral head. The elevation of the tip of the greater trochanter was not accounted for.

GOFF (1954) and HORWITZ (1960) published radiographs of elevated greater trochanters but did not discuss the cause of the elevation.

Observations on the present material

In the present series no radiological changes indicative of necrosis were observable in the greater trochanter.

As appeared in the foregoing, retardation of the longitudinal growth of the femoral neck and premature closure of the subcapital epiphyseal line

are of frequent occurrence in coxa plana As a rule the growth of the greater trochanter was not affected by the process Since the longitudinal growth of the femoral neck may cease completely at the age of 12 to 14 years while the growth of the greater trochanter continues until the age of 17 to 18 years and sometimes longer it is obvious that a discrepancy between the femoral head and neck on the one hand and the greater trochanter on the other must result On the radiographs this was discernible as a reduction of the distance between the tip of the greater trochanter and the proximal pole of the femoral head In the present paper this distance is called the *articulo-trochanteric distance*

For the sake of assessing the influence of the process of the disease in coxa plana on the articulo-trochanteric distance measurements were made on the radiographs For this purpose perpendiculars were drawn against the longitudinal axis of the femoral diaphysis so as to touch the proximal pole of the femoral head and the tip of the greater trochanter The distance between these perpendiculars was measured in millimetres In what follows it is denominated ATD (Fig 26) If the tip of the greater trochanter was situated distally of the proximal aspect of the femoral head the ATD was regarded as positive It was regarded as negative when the tip of the greater trochanter was situated proximally of the proximal aspect of the head of the femur

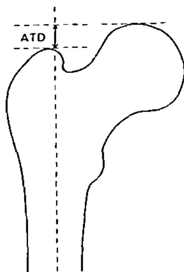


Fig *r* Determination of the articulo trochanteric distance ATD

In order to find out to what extent the ATD is influenced by different rotational positions of the femur frontal radiographs were taken of 12 hip joints in the neutral position and in 20 degrees outward and inward rotation The radiographs were taken by the same technique as was used in examining the coxa plana patients In addition a specimen was radiographed in the same way As compared with the neutral position the ATD was found to increase on outward rotation and decrease on inward rotation The results of these tests are shown in Table 32 Although the differences were small they may have influenced the measurements in the present *series to some degree The errors were reduced however by the* radiographic technique which was elaborated so as to attain the greatest possible degree of standardization of the projections The severest deformities involving the largest reductions of the ATD were often associated with a slight outward rotation of the extremity and a limitation of the 20 degrees inward rotation which is a condition of our standard technique The readings for the ATD therefore represent maximum values

TABLE 32 — *ATD in 12 normal hip joints and in a specimen in the neutral position outward rotation and inward rotation*

	Articulo trochanteric distance	
	Mean in 12 normal hips mm	Specimen mm
Neutral position	21	18
Outward rotation	24	20
Inward rotation	19	14

The results obtained after the completion of growth in 81 unilateral cases of coxa plana are shown in Table 33

TABLE 33 — *ATD in unilateral coxa plana after completion of growth in relation to shape of the femoral head*

Shape of the femoral head	Articulo trochanteric distance				
	Affected hips		Unaffected hips		No of cases
	Mean	(Range)	Mean	(Range)	
Spherical	11 7	(+21— — 9)	16 0	(+24— + 6)	23
Elliptical	1 7	(+13— — 4)	15 9	(+28— +11)	17
Irregular	2 2	(+17— —19)	15 1	(+28— + 8)	41

The results obtained in the same group at an earlier stage of the disease before closure of the subcapital epiphyseal line are shown in Table 34

Table 35 shows the results of measurement after the completion of growth in 20 bilateral cases of coxa plana

From Tables 33 and 34 it appears that no reduction of the ATD was primarily present (it occurred at a late reparative stage in part only when the femoral head had attained its final shape) The reduction of the ATD increased with poorer end results in the head although it was sometimes marked also in cases healing with a spherical head

TABLE 34

Shape of the femoral head	Articulo trochanteric distance			
	Affected hips		Unaffected hips	
	Mean	(Range)	Mean	(Range)
Spherical	17 2	(+24— + 5)	16 8	(-2[illegible]— — 8)
Elliptical	14 8	(+18— +12)	16 9	(+22— +12)
Irregular	14 1	(+2[illegible]— + 5)	16 4	(+30— + 8)

TABLE 35 — *ATD in relation to ultimate shape of the femoral head after completion of growth in 20 cases of bilateral coxa plana*

Shape of the femoral head	Articulo trochanteric distance		No of hips
	Mean	(Range)	
Spherical	10	(+18— — 3)	13
Elliptical	8 8	(+15— + 1)	4
Irregular	0 9	(+2[illegible]— —19)	23

In Table 36 the ATD in the group with unilateral coxa plana showing premature closure of the epiphyseal line is compared with the ATD in the group showing normal closure It is seen in the table that the ATD was markedly reduced in the group showing premature closure In the group showing normal closure the reduction of the ATD was slight as compared with the unaffected side Fig 27 shows the results of measurement of the ATD in these groups

TABLE 36 — *ATD in unilateral ultimately healed coxa plana with premature closure (42 cases) and normal closure (20 cases) of the subcapital epiphyseal line*

Closure of the epiphyseal line	Articulo trochanteric distance				No of hips
	Affected hips		Unaffected hips		
	Mean	Range	Mean	Range	
Premature	1 3	+13— —11	16 2	+28— +5	42
Normal	13 7	+23— + 5	15 4	+21— +6	20

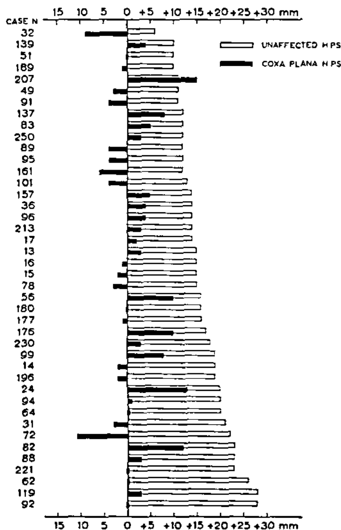


Fig a

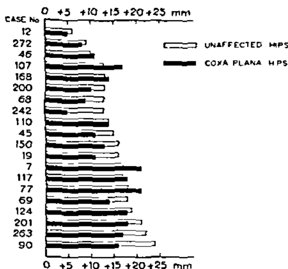


Fig 7 b

Fig 7 a the articulo-trochanteric distance in 42 cases showing premature closure of the epiphyseal line and *b* in 20 cases showing normal closure of the epiphyseal line

Case 230 in the present series is a typical example of reduction of the ATD *in connexion with premature closure of the subcapital epiphyseal line* The essential data are listed in Table 37

The series includes 7 cases in which the radiographs were indicative of premature and simultaneous closure of the subcapital growth line and the growth line of the greater trochanter In these cases 5 of which healed

TABLE 37 — *Reduction of ATD in a typical case of coxa plana Case 30 Boy aged 8 at onset in Sept 1957 Right side affected*

Date	Right hip Condition of the epiph lines		ATD		Left hip Condition of the epiph lines	
	Subtro-chanteric	Subcapital	Right	Left	Subcapital	Subtro-chanteric
April 1959	Open	Open (Reparat st)	+ 15	+ 16	Open	Open
April 1960		Very irregular	+ 14	+ 15		
Oct 1960		Partly closed	+ 12	+ 16		
April 1961		More closed	+ 10	+ 15		•
Oct 1961		Almost closed	+ 8	+ 17	•	•
Oct 1962		Closed	+ 3	+ 18	Partly closed	•
Jan 1964	Closed		+ 3	+ 18	Closed	Closed



Fig 8 a—b

with irregular femoral heads 1 with an elliptical and 1 with a spherical femoral head no major reduction of the ATD occurred On the affected side this distance was a mean of 14 6 mm (the range being from +9 to +26 mm) and on the unaffected side a mean of 15 9 mm (the range being from +7 to + 25 mm) In some of these cases the premature closure of the epiphyseal line of the greater trochanter was apparently due to the epiphysis having grown out over the cranial aspect of the femoral neck so as to come into contact with the trochanter at its base close to the epiphyseal line It may be assumed that vascular anastomoses between the epiphysis of the trochanter and the metaphysis had been established with fusion of the growth line resulting in the same way as in the subcapital region In some cases this mechanism was obviously not responsible however and the radiographs afford no explanation of the premature closure of the growth line of the greater trochanter

From the observations made in the present series concerning the growth of the proximal part of the femur the conclusion may be drawn that *the*



Fig 28 Case 161 girl aged 7 years at onset Treated for 9 months with Thomas splint in an advanced stage of the disease *a* September 1954 late reparative stage the epiphyseal line very irregular *b* August 1956 primary healing the subcapital epiphyseal line partially closed ATD + 11 mm on the left side + 16 mm on the right side Trendelenburg's sign negative *c* October 1959 the subcapital epiphyseal line closed the subtrochanteric epiphyseal line still open ATD left — 3 mm right + 12 mm Trendelenburg's sign positive to the left *d* February 1963 all growth lines closed ATD left — 6 mm right + 12 mm The left femoral head slightly irregular enlarged Normal mobility in the left hip Trendelenburg's sign positive

elevation of the greater trochanter in coxa plana is due to retardation of the longitudinal growth of the femoral neck and premature closure of the subcapital epiphyseal line while the growth of the greater trochanter proceeds as normal throughout the remainder of the growing period

Fig 28 (case 161) illustrates the elevation of the greater trochanter associated with premature closure of the subcapital epiphyseal line

IX THE DEFORMITY IN COXA PLANA

VARUS OR VALGUS

Earlier observations According to HOFMEISTER's (1894) definition coxa vara is present if the neck-shaft angle is smaller than normal (120 degrees in adults v LANZ-WACHSMUTH 1938) This definition does not take the greater trochanter into account which is an integrating part of the proximal end of the femur and derives its epiphyseal plate from the same preplate as the femoral head (see p 23) SOURDAT (1909) and CALVE (1910) stated that coxa plana leads to a varus deformity WALDENSTROM (1910) who observed no appreciable alteration of the neck shaft angle in coxa plana did not regard the deformity caused by the disease as a varus deformity but he pointed out that an apparent varus deformity may result if the medial portion of the femoral head grows in the medio caudal direction Many other authors have adopted the same view *e g* HORWITZ (1960) and LEGER (1961) The latter wrote »Die Perthesche Erkrankung ist zu der durch Wachstums storungen bedingten Coxa vara im engeren Sinne nicht zu rechnen» GOFF (1954) reported that he had not observed any varus deformity in his series except in the group »irregular type» in which no coxa vara was present at first but sometimes developed soon enough as an osteomalacia of a local character

SUNDT (1949) measured the neck shaft angle on the radiographs taken at follow up investigation of his series He found that the angle was almost invariably enlarged and concluded »The disease has thus an unmistakeable tendency to produce a valgus position of the neck »

PERTTILA (1951) too measured the neck shaft angle and found that the coxa valga type was clearly prevalent when the determinations were made on neutral position radiographs He emphasized however that the values obtained by this method were too high It seems probable that the large neck shaft angles noted by SUNDT were also due to the fact that the measure ments were made on radiographs taken in the neutral position or possibly in outward rotation

PERTTILA regarded functional coxa vara as being present in those cases where the greater trochanter is elevated

EVANS (1958) determined the neck shaft angle in a series of 52 patients A valgus deformity was present in 6 cases in which the angle was increased by over 10 degrees as compared with the unaffected side In no case was any marked varus deformity noted The author pointed out that marked shortening of the head neck segment is shown clinically by elevation of the greater trochanter

In the present series no major changes of the neck shaft angle were observed The measurements were made on radiographs taken in 20 degrees inward rotation

LANGENSKIOLD & SARPIO (unpublished) and LAURENT (1959) showed in animal experiments LAURENT (1959) and PYLKKANEN (1960) in clinical series that a coxa vara deformity developed when the activity of the subcapital epiphyseal plate was disturbed or prematurely came to a standstill while a coxa valga deformity resulted when the activity of the epiphyseal plate of the greater trochanter was disturbed or prematurely ceased

Discussion In the *distal end of the femur* the epiphysis consists of two condyles originating from a common growth plate If the growth process is inhibited in the growth zone of the medial condyle while the lateral condyle continues to grow a varus deformity develops *Vice versa* if the growth of the lateral condyle is inhibited a valgus deformity results

In certain mammals *e g* the elephant the preplate is not differentiated into a separate epiphyseal plate for the femoral head and another for the greater trochanter The head and the trochanter grow from the same growth plate (LUTKEN 1961) In rare cases a bony bridge is formed between the capital epiphysis and the bony nucleus of the trochanter in man so that a common uniform epiphyseal plate for the femoral head and the greater trochanter develops LUTKEN described 3 such cases and MAU (1962) also described 3 At the Orthopaedic Hospital of the Invalid Foundation I have observed 2 such cases in which the formation here described developed after closed reduction of a congenital hip luxation (Fig 29) In such cases similar conditions prevail in the proximal and distal ends of the femur which justifies a comparison of these structures The head and the greater trochanter may be compared with the two condyles If the growth of the medial subcapital region is arrested while the lateral trochanteric area continues to grow a varus deformity develops and *vice versa* if the growth of the trochanteric region is arrested while the subcapital region continues to grow a valgus deformity results

IX THE DEFORMITY IN COXA PLANA

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X TRENDELENBURG's SIGN

Earlier investigations

The greater trochanter is the site of insertion of the abductors of the femur in the first place the gluteus medius and gluteus minimus From the stand point of the function of the pelvitrochanteric abductor muscles and the statics in the pelvic hip region the position of the greater trochanter in relation to the pelvis is of fundamental importance In the presence of a coxa vara deformity *e g* in coxa vara infantum the function of the pelvitrochanteric abductors is impaired owing to elevation of the greater trochanter The abductor insufficiency is manifested by a positive Trendelenburg sign (v LANZ WACHSMUTH 1938 PYLKKÄNEN 1960)

Limping is a constant early symptom in coxa plana This form of limp was described by CALVE *et al* (1939) as »antalgic gait» and it differs from Trendelenburg s type At the time of primary healing the limp if there is any is of a neutral type due to shortening of the limb (CALVE *et al* 1939 GOFF 1954) If the disease leads to a varus deformity *i e* if the greater trochanter is elevated in relation to the hip joint and if abductor insufficiency develops the limp is of Trendelenburg s type

Observations on the present material

In the present series a positive Trendelenburg sign was noted in 26 cases of ultimately healed unilateral coxa plana In 15 of these the ATD was 0 or negative *ad* — 9 mm In 9 cases the ATD varied between + 1 and — 5 mm In 1 case the ATD was + 8 mm in the coxa plana hip against + 23 mm in the unaffected hip which implies a marked reduction In 1 case no appreciable reduction of the ATD was demonstrable (+ 12 mm against + 13 mm in the unaffected hip) In this case the positive Trendelenburg sign must be attributed to some other cause than reduction of the ATD probably to muscular insufficiency

Among the 26 cases with positive Trendelenburg signs there were 9 in which a retrospective examination of the clinical data and the radiographs

revealed that Trendelenburg's sign had been negative at a late reparative stage of the disease and that no or only a slight reduction of the ATD had then been present (Fig 28)

As far as the shape of the femoral head is concerned the radiological end results were mostly poor in this group Two cases healed with spherical heads 7 with elliptical and 17 with irregular heads

The present observations in the cases with positive Trendelenburg signs show that *abductor insufficiency in coxa plana may develop at a very advanced stage of the disease as a result of elevation of the greater trochanter*

XI PREVENTION OF DEFORMITY BY EPIPHYSIODESIS OF THE GREATER TROCHANTER

In 1961 epiphysiodesis of the greater trochanter was performed at the Orthopaedic Hospital of the Invalid Foundation in 3 cases of coxa plana In 2 of these the ATD was markedly reduced at the time of the operation i e + 2 and — 1 mm in the affected hips against + 12 and + 1 mm on the unaffected side In the latter case moderate bilateral coxa vara was already present at the time of the diagnosis The deformity was probably due to rickets In the third case epiphysiodesis was performed at a late reparative stage On the affected side the subcapital epiphyseal line was partially closed but the ATD was not reduced it was + 12 mm on both sides The operation was performed by Phemister s (1933) method first applied to the greater trochanter by A Langenskiold in 1957 (personal communication)

On follow up examination of these patients 17 22 and 11 months respectively after operation the growth line of the greater trochanter was found to be closed in all cases In the first two cases the reduction of the ATD had increased by 2 mm on the side operated upon and was thus 0 and —6 mm respectively Trendelenburg s sign was in these cases weakly positive In the third case the ATD had been enlarged by 1 mm and was + 13 mm on *both* sides Trendelenburg s sign was negative

During the years 1963 and 1961 epiphysiodesis of the greater trochanter was performed in 20 unilateral and 2 bilateral cases of coxa plana in which radiological studies revealed progressive reduction of the ATD or premature closure of the subcapital epiphyseal line Thirteen of these cases do not belong to the present series

In Table 38 the principal data regarding the patients operated upon are compiled

Discussion

It appears from Table 36 that the reduction of the ATD was arrested by epiphysiodesis of the greater trochanter In the cases which were followed up the postoperative reduction of the ATD was a maximum of 2 mm except in 2 cases (J K and J Y) in which the ATD had been reduced by 4 and 3 mm respectively In the bilateral case L J the ATD on the operated right side decreased by 1 mm during the time of observation while the reduction of the ATD on the non-operated left side was 13 mm during the same period In 8 cases the ATD had been enlarged by 1 mm

In all cases which have been followed up the epiphysiodesis led to partial or complete fusion of the growth line of the trochanter (Fig 31)



Fig 31 Case M L R (not in the present series) girl aged 6 years at onset *a* in June 1964 five and a half years after onset the subcapital epiphyseal line is partially closed on the affected left side ATD is + 3 mm and had decreased from + 7 mm in Dec 1962 Epiphysiodesis of the left greater trochanter was performed in June 1964 *b* Oct 1964 The subtrochanteric epiphyseal line is closed on the left side ATD is + 4 mm on the left side and + 8 mm on the right side as was the case at two previous examinations Trendelenburg s sign was negative

In many cases the operation was performed late when marked elevation of the greater trochanter was already present

If epiphysiodesis of the greater trochanter is performed at a favourable point of time it appears to be possible to prevent elevation of the trochanter and consequent abductor insufficiency

TABLE 38 — *Coxa plana cases in which epiphysiodesis*

Case	Year of birth	Stage of process at time of oper	Condition of epiphyseal line at time of oper		Articulo tro		
					At time of operat		Time of oper
			Subcapital	Sub trochant	Unaf fected hip	Affected hip	
L M I	1947	Late repar	Part closed	Open	+12	+ 2	Oct 1961
M U	1947	Repar	•		+ 4	— 4	
A N	1947	Late repar		•	+12	+12	Nov 1961
I K	1952	Repar	Open irreg		+18	+12	Feb 1963
I J	1949	R Prim heal	Closed		—	+ 7	Mar 1963
		I			—	+16	Un oper
A T	1948	Late repar			+19	— 4	June 1963
I A	1950	Prim heal	•		+11	— 3	Oct 1963
R L	1952	Repar	Open irreg		+10	+ 1	Jan 1964
J Y	1950	Late repar			+15	+11	
I A	1952	Prim heal	Part closed	•	+22	+ 8	Feb 1961
I S	1950	Late repar	Open irreg		+14	+11	Mar 1961
A N	1949	Prim heal	Part closed		+14	+ 3	•
I M	1951	R Repar	Closed		—	0	
		L Prim heal			—	0	
P K	1953	Repar	Open irreg	•	+16	+ 2	•
I M	1953	Prim heal	Part closed		+15	+ 9	May 1964
M L R	1953	Late repar			+ 8	+ 3	June 1961
F K	1950	Prim heal	Closed		+25	+ 6	July 1961
O A	1950	Repar			+11	+ 8	
A A	1951	Late repar	Part closed	•	+17	+ 1	
A M L	1951	Prim heal			+13	+ 4	
R Y	1955	Late repar		•	+17	+12	Aug 1961
A R	1954				+14	+ 5	Sept 1961
R A	1954	Prim heal	Open irreg		+11	— 1	
I M	1955	Repar			+16	+15	Oct 1964
H S	1953				+12	+10	

of the greater trochanter was performed

chanteric distance		Condition of epiphyseal line after operation		Observation time after operation in months
After operation				
Affected hip	Unaffected hip	Subcapital	Subtrochanteric	
0	+13	Closed	Closed	17
− 6	+ 2			31
−13	+13			11
− 8	+15	•	Part closed	19
+ 6	—		Closed	15
+ 3	—		Open	15
				—
− 4	+14		Closed	11
+ 2	+ 9	Part closed	Part closed	10
+ 8	+15	•		6
+ 6	+19			10
−11	+14	Open irreg	•	12
+ 4	+15	Closed	Closed	9
+ 1	—			6
− 2	—			6
+ 3	+16	Open irreg		6
+ 8	+16	Part closed		4
+ 4	+ 8	Closed		4
+ 7	+26			3
+ 8	+11	Part closed		3
+ 1	+17	Closed		7
+ 3	+13			4
+11	+16			6
+ 4	+15	Part closed	•	8
				—
−16	+16	Open irreg		5
−10	+12			5

XIII SUMMARY

The study was carried out on a series of patients registered at the Radiological Department of the Orthopaedic Hospital of the Invalid Foundation during the years 1946—1958 The series comprised 276 cases from the whole of Finland Fifty cases being bilateral the total number of coxa plana hips was 326 The ratio of males to females was 1 1 A slight preponderance for left sided lesions was noted The youngest patient was 2 years and 8 months old the oldest 14 years at onset of the disease The highest frequency was observed in the age group 6—7 years The mean duration of symptoms at the time of diagnosis was 9 6 months Of the cases of active coxa plana 18 3 per cent were diagnosed in the initial stage

Treatment The treatment was conservative and mostly consisted of weight relief on the affected side accomplished with Thomas splint and elevation of the opposite shoe In 27 cases the treatment by Thomas splint was preceded by some weeks hospitalization during which the walking caliper was manufactured and fitted and the patient was instructed in its use A small number of patients were treated by bed rest or by non weight bearing with crutches at home The mean duration of non weight bearing was 2 3 years

End results The end results were classified into spherical head = good elliptical head = fair and irregular head = poor result In a total of 16[illegible] treated hips the result was good in 49 1 per cent fair in 21 2 per cent and poor in 29 7 per cent When end results and onset age were correlated the results were found to be clearly better in the younger age groups Furthermore it was found that the shorter the duration before the institution of treatment and the earlier the stage of the disease when treatment was instituted the better were the results

Conditions resembling *osteochondrosis dissecans* were observed in 16 hips *i e in 5 2 per cent of the hips* with coxa plana examined In 7 of these cases there was a history of trauma suggestive of a causal relationship

Aetiological factors In 3 6 per cent of the present cases the disease was preceded by a single trauma which may be considered directly related to the

development of coxa plana In 5 cases the disease was preceded by general or localized infection which may be regarded as a factor of aetiological significance Radiologically verified coxa plana was encountered in 11 close relatives of those patients numbering 172 who were particularly questioned on this point This high frequency (6 4 per cent) seems to indicate that hereditary factors play a part in the development of the disease

The course of the radiological changes In the present series the mean duration of the initial stage was 5 6 months The duration of the initial stage was independent of the onset age

The mean duration of the fragmentation stage was 10 8 months A lower onset age did not seem to shorten the duration of the fragmentation stage

The mean duration of the reparative stage was 32 months The duration of reconstruction was somewhat shorter in the younger than in the older age groups

The mean duration of the disease was 4 years and 4 months counted from the onset of illness until primary healing had taken place

In mild abortive cases no changes were detectable in the metaphysis In some cases with slight or moderate signs of fragmentation in the epiphysis slight reversible metaphyseal changes were observed During the initial stage the most frequent metaphyseal change was a band shaped zone of demineralization across the proximal portion seen on the frontal view This zone represents a defect in the ventral margin of the metaphysis seen on the lateral view (Fig 13 p 71) During the fragmentation stage the defect was enlarged and gradually developed into an oblique or most often a step shaped defect owing to the fact that the ossification of the central portion of the metaphysis continued while growth was arrested in the area of the defect (Fig 21 p 86) The metaphyseal surface developed a proximally directed convexity During the reparative stage the metaphyseal defect was filled out by the epiphysis (Fig 21) In occasional cases with severe metaphyseal changes the metaphyseal defect disappeared owing to reformation of bone at its margins In such cases the metaphyseal surface was levelled and the epiphyseal line became regular (Fig 16 p 78—79) The epiphysis showed a tendency to grow out over the metaphysis with broadening of the epiphysis resulting Parallel with the ossification of the metaphyseal defect and the epiphysis an increase in breadth of the metaphysis occurred Inhibition of the longitudinal growth of the femoral neck was observed

Various degrees of irregularity of the proximal surface of the metaphysis were observable Tomograms were very informative in this respect (Fig 17

p 80—81) Towards the end of the reparative stage the epiphyseal line became thinner Partial and gradually total fusion of the epiphyseal line often occurred earlier on the affected side than on the unaffected side As a consequence of this asymmetrical growth with malposition of the head in relation to the neck resulted in some cases (Fig 20 p 83)

Severe metaphyseal changes are often associated with poor healing of the femoral head premature closure of the subcapital epiphyseal line broadening of the metaphysis and shortening of the femoral neck

Formation of a step in the metaphysis Step shaped metaphyseal defects have previously been described in tibia vara (Fig 22 p 88) and after osteomyelitis or tuberculosis (Fig 21 p 89) of the long bones Similar metaphyseal defects have been produced in animal experiments (Fig 23 p 89) In juvenile osteochondrosis of the lumbar vertebrae ossification defects have been observed which resemble the above mentioned A feature in common to all these defects appears to be that growth is arrested locally while it continues in the surroundings Initially the metaphyseal defects are filled out by cartilage As ossification continues the metaphyseal defects are often filled out by the bony epiphysis The development of the metaphyseal defects observed in the present series of coxa plana as studied on the basis of radiographs showed a striking resemblance to the course described above

On the basis of the scanty observations previously reported concerning the histological changes of the epiphyseal plate in coxa plana and in necrosis following a fracture of the femoral neck in adolescence and on the basis of reports on extensive necrosis of the epiphyseal cartilage in connexion with experimental epiphyseal transplantation it seems obvious that necrosis of the cartilage tissue in the epiphyseal plate is a pathogenetic factor in common to the development of metaphyseal defects of the kind described here

The pathogenesis of coxa plana It is a generally accepted view that the coxa plana process is histopathologically an avascular necrosis The primary cause of the vascular disturbance is still obscure

On the basis of earlier investigations concerning the circulatory conditions in the proximal part of the femur in the coxa plana age the bony epiphysis is supplied only by the lateral epiphyseal arteries departing from the medial circumflex artery The central portion of the metaphysis is supplied by the nutrient artery the peripheral parts by the superior and inferior metaphyseal arteries which are branches of the medial circumflex artery In coxa plana the lateral epiphyseal vessels and probably the metaphyseal vessels are obstructed owing to a cause not yet established the result being

necrosis of the epiphysis and corresponding areas of the epiphyseal cartilage and the metaphysis Radiologically this is evidenced by condensation flattening and fragmentation of the epiphysis and a defect in the periphery of the metaphyseal surface The central part of the metaphysis supplied by the nutrient artery continues to grow The reossification of the epiphysis starts in the periphery after revascularization via the synovial membrane The fate of the metaphyseal defect is dependent on the severity of the cartilage lesion in the epiphyseal plate If the lesion is slight ossification commences at the margins of the metaphyseal defect If the lesion is severe the metaphyseal defect remains and is gradually filled out by the bony epiphysis The lesion in the epiphyseal plate is often of such a kind that contact is established between the vascular systems in the epiphysis and the metaphysis with local fusion of the epiphyseal line resulting

The greater trochanter Retardation of the longitudinal growth of the femoral neck and premature closure of the subcapital epiphyseal line are of frequent occurrence in coxa plana As a rule the growth of the greater trochanter is not affected It is thus obvious that a discrepancy between the femoral head and neck on the one hand and the greater trochanter on the other must result On the radiograms this is discernible as a reduction of the distance between the tip of the greater trochanter and the proximal pole of the femoral head in the present paper called the articulo-trochanteric distance ATD (Fig 26 p 95)

In the present study systematic measurements of the ATD were made It emerged that the reduction of the ATD which implies elevation of the greater trochanter occurred late in the reparative stage or after primary healing had taken place in those cases where the subcapital epiphyseal line fused prematurely In many cases the elevation of the greater trochanter was so marked that the tip of the trochanter reached several millimetres higher cranially than the upper pole of the head of the femur

The deformity in coxa plana The deformity caused by coxa plana has been discussed in the previous literature Some authors believe that the disease leads to a varus deformity while according to others it tends to cause a valgus deformity In these estimates the part of the greater trochanter in the modelling of the proximal end of the femur has been disregarded The greater trochanter is however an integrating part of the proximal end of the femur and cannot be ignored on assessing a possible varus or valgus deformity of the latter

An account is given of previous experimental and clinical observations on growth phenomena in the proximal end of the femur associated with distur

bances in the subcapital or subtrochanteric growth zones and a comparison is made with the conditions prevailing in the distal end of the femur The conclusion is drawn that in those relatively frequent cases of coxa plana in which the subcapital growth line is prematurely closed and the growth of the greater trochanter continues undisturbed throughout the normal growing period the ultimate deformity of the proximal end of the femur is a true varus deformity

Trendelenburg s sign In the present series a positive Trendelenburg sign was noted in 26 cases of ultimately healed unilateral coxa plana The ATD was reduced in all but one of these cases Among the 26 cases there were 9 in which a retrospective examination of the clinical data and the radiographs revealed that Trendelenburg s sign had been negative at a late reparative stage and that no or only a slight reduction of the ATD had been present The observations in the cases with positive Trendelenburg signs show that abductor insufficiency in coxa plana may develop at a very advanced stage of the disease as a result of elevation of the greater trochanter

Prevention of deformity by epiphysiodesis of the greater trochanter Since 1961 epiphysiodesis of the greater trochanter has been performed at the Orthopaedic Hospital of the Invalid Foundation in 25 cases of coxa plana in which radiological examinations revealed progressive reduction of the ATD or premature closure of the subcapital epiphyseal line In 23 cases which have been followed up the epiphysiodesis led to partial or complete fusion of the growth line of the trochanter and the reduction of the ATD was arrested by the operation These results seem to justify the conclusion that if epiphysiodesis of the greater trochanter is performed at a favourable point of time it appears to be possible to prevent elevation of the greater trochanter and consequent abductor insufficiency

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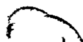
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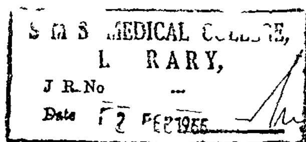
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Surgical Treatment of Spondylolisthesis without Spine Fusion



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Surgical Treatment of Spondylolisthesis without Spine Fusion

A Long Term Follow-up of Operated Cases

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Eight years ago in association with *Manning* the authors reported a group of eighteen patients treated for symptomatic spondylolisthesis by excision of the loose lamina and decompression of the nerve roots without spine fusion (5). The patho-mechanics of this condition, the surgical technique, the findings at surgery, and the methods of postoperative care were described at that time.

The present paper is a long term follow up study of our operated cases in which we shall pay particular attention to the question of postoperative progression of displacement and our results.

Our series now consists of fifty two patients between the ages of fourteen and fifty-seven years. The two children in the group were fourteen years of age. Forty three patients (twenty-one males and twenty two females) were treated initially by the decompression operation. Two women had a combined decompression and fusion and seven women were treated by the decompression procedure after previous fusion operations had failed to relieve their symptoms. Of the latter six had pseudarthroses but one had persistent symptoms despite a solid fusion.

The present length of follow up on all of our patients extends from four to 146 months and averages sixty four months. Twenty nine cases have been followed over sixty months. Sixteen cases were lost after follow up periods of four to thirty seven months. Ten of these have not been seen since our initial publication. Therefore their radiographs have not been included in this article (Cases 1, 6, 8, 9, 10, 11, 12, 17, 19 and 20).

EVALUATION OF DISPLACEMENT

Most of our early x rays were obtained with the patients reclining. All of the follow up x rays were taken in the upright position. Comparisons between the reclining and upright films obtained on the same date show no essential change in the position of the involved vertebra

We used *Taillard's* method (9 10) of expressing the displacement of the spondylolisthetic vertebra as a per cent of the width of the vertebra below This is illustrated in Table 3 The description of the degree of displacement follows *Meyerding's* basic classification but is more detailed and is described in footnotes on Tables 1 E and 2 E

PROGRESSIVE FORWARD DISPLACEMENT IN THE CHILD

Friberg (3) reported that progressive forward displacement occurred over a relatively short period of time in a very few children in his series and in these cases spondyloptosis resulted

Taillard showed that progressive forward slipping occurred in twelve of the fifty cases in his series and only in patients under the age of twenty five years He believed that he could accurately predict rapid and complete forward displacement in those patients having both a decrease in the posterior vertical height of the fifth lumbar vertebra of 30 per cent or more in relation to the anterior height and a rounding of the superior border of the sacrum He reduced the deformity by Scherb s method obtained satisfactory repositions in seven of the thirteen cases attempted and performed postero-lateral fusions in these cases Of these seven cases six subsequently showed complete forward displacement He concluded that successful arthrodesis was ineffective in preventing progressive displacement

In our original paper we were aware that rapid forward displacement occurred in some children and we advised against the decompression procedure in children *Margo* (7) later reported the case of a young boy with considerable displacement whose symptoms were temporarily relieved by the decompression operation but who then showed additional displacement and developed more symptoms *Marmor & Bechtol* (8) reported an almost identical case In both of these cases fusions were performed after the slipping had progressed but unfortunately the lengths of follow up were brief

Taillard's criteria would have indicated the probability of progressive displacement in these two patients In our opinion removal of the arch contributed nothing to the increased displacement nor in most hands would initial fusion have prevented it

One of the two children in our series (Case 51) showed the typical changes mentioned by *Taillard* This boy had low back and leg pain and was treated with exercises until spondyloptosis occurred At sur

gery solid healing of the defect on the left and evidence of partial healing on the right were found In addition there was a spontaneous fusion of the inferior facet of the fifth lumbar vertebra to the sacrum on the left The decompression operation was performed and resulted in complete relief of symptoms He had some recurrence of difficulty fifteen months after surgery following an automobile accident but symptoms quickly subsided

The other child (Case 50) did not show the progressive displacement criteria of *Taillard* She was treated conservatively however for twenty eight months and no progression occurred At surgery no defect was demonstrable in either pars interarticularis or pedicle The lower end of the dural sac and the sacral nerve roots were compressed by a tight arch of the fifth lumbar vertebra A simple laminectomy was performed and the inferior facets were left intact She had relief *of symptoms after surgery For nine months there was no further* displacement but x rays twenty four months after surgery revealed a 22 per cent progression of displacement The patient was entirely asymptomatic however and the clinical examination was completely negative

In our experience most children become asymptomatic on a vigorous program of straight leg raising and toe touching exercises However if symptoms are persistent and severe we feel that the decompression operation may be done for relief of pain in most children since only one child out of ten is likely to show progressive displacement and since it now seems probable that we can predict which children will continue to slip

We believe there are two alternatives in those children who do have x ray findings indicative of continuing displacement If both arthrodesis and arrest of displacement could always be achieved then one would certainly be justified in doing a combined decompression and fusion operation particularly in females However if one could not be certain either of arresting displacement or of obtaining solid fusion as we cannot then one should inform the parents that further progression is likely and that surgery should be delayed until maximum displacement is reached We recommend deferring surgery because in some cases of severe displacement it is also necessary to excise the lamina above the spondylolisthetic vertebra to achieve a thorough decompression

PROGRESSIVE DISPLACEMENT IN THE ADULT

Twenty nine of our fifty adult patients have shown no postoperative progression of forward displacement after an average follow up of fifty nine months The remaining twenty one adults have shown varying amounts of progressive displacement during an average follow up period of eighty one months (See Tables 4 and 5) The average postoperative increase in displacement in all of our patients including the children is 5 per cent

Although this series of cases is too small to be of statistical value it is at least interesting to note that essentially the same percentage of men and women showed progression of displacement after surgery In the group showing progression the average increase was 5 9 per cent in males and 16 per cent in females Among the women Cases 2 5 16 18 25 29 and 50 showed the greatest progression and all but one were young Case 5 had two children before surgery and three afterward Case 16 had three children after surgery and Case 18 had one before the decompression and one afterward Cases 5 and 18 reported much easier pregnancies and deliveries after the decompression operation None of these women had any back difficulty during pregnancy or any complications with delivery

In the adults showing increase in slipping there were 90 per cent satisfactory results and 10 per cent failures whereas there were 82 7 per cent satisfactory cases and 17 3 per cent failures in the group who showed no progression These figures substantiate our opinion that there is no correlation between symptoms and the degree or progression of displacement in adults with spondylolisthesis

Case 5 a woman who has been followed for 123 months is of particular interest to us because she has shown considerable progression of displacement (27 per cent) and because we obtained follow up x rays on her at close enough intervals to learn when the progression occurred *Tracings of the x rays appear in* Table 3 Progression was first noted thirty eight months after surgery and was associated with narrowing of the lumbosacral disc The progression and narrowing continued over the next forty three months until the disc collapsed completely Displacement has not progressed in the past three years but seemingly has regressed 6 per cent During the period of increasing displacement this patient had no symptoms After the disc collapsed and displacement stopped she began to have episodes of back and leg discomfort after lying in bed for several hours She could obtain relief

by getting up and exercising This patient certainly did not fit the typical clinical picture of so-called instability since the erect position and activity relieved the symptoms which she had

Aside from Case 5 x rays were not taken at the proper intervals to show precisely when progression of displacement occurred in the other adults It would appear however from the patients whom we have followed for a long period of time (Cases 2 4 5 13 15 16 28 and 29) that progression of displacement after the decompression operation is generally mild occurs in association with narrowing and degeneration of the lumbosacral disc and in itself does not cause symptoms

Adkins (1 2) described two patients who showed some increase in forward displacement after excision of the arch In each case he removed the posterior annulus of the disc in order to perform an inter body fusion which then could not be done because of deterioration in the patient s condition during surgery He felt that removal of the posterior annulus might have been the cause of the additional dis placement which later occurred

The preservation of the posterior annulus may therefore be im portant to the maintenance of stability in this condition Also the build up of bone along the anterior superior portion of the sacrum which is frequently seen in patients with spondylolisthesis may well be due to the stripping away of the annulus from this portion of the sacrum

SPONTANEOUS HEALING OF THE DEFECT

Several cases listed on Table 1 C had a build up of bone about the defects in the pars interarticularis which seemed to indicate attempted healing and in four patients we found evidence of complete healing

In Case 24 the defect on the right showed healing by bone In Case 42 although the appearance by x ray was characteristic of a typical first degree spondylolisthesis at surgery both defects were found to be completely filled in with bone Symptoms in this case were obviously caused by the massive bone formation which compressed the fifth lumbar roots at the sites of the healed defects This patient also had a spontaneous fusion of the inferior facet of the fifth lumbar vertebra to the superior facet of the sacrum on the left

Case 50 had the typical appearance of spondylolisthesis but at surgery no defects were found in the arch and the symptoms appeared to be due to compression of the sacral nerve roots and the dural sac by the tight arch

Despite the rapid occurrence of spondyloptosis before surgery in Case 51 the defects in the fifth lumbar vertebra were found to be healed completely on the left and partially on the right This patient also had a spontaneous unilateral fusion of the inferior facet of the fifth lumbar vertebra to the sacrum on the left

A spontaneous and very solid fusion of both inferior facets of the fifth lumbar vertebra to the sacrum was also found in an adult with spondyloptosis (Case 28)

DEVELOPMENT OF PSEUDARTHROSIS FOLLOWING SOLID FUSION

We have found that patients with spondylolisthesis may develop pseudarthrosis even many years after apparent solid fusion is present

Case 3 was treated initially in 1949 by a *Hibbs* fusion from the fourth lumbar vertebra to the sacrum without decompression Four teen months later because of persistent left leg pain a re exploration was carried out for removal of the fibrocartilaginous mass which was felt by that time to be the cause of her symptoms The fusion was found to be heavy and solid A hole was drilled through the one inch thick fusion mass on the left side at the fourth lumbar interspace to gain exposure of the defect Seventy four months following the initial fusion a pseudarthrosis developed at the lumbosacral interspace Inter estingly enough however the fusion remains solid at the fourth lumbar level

Another patient (Case 27) had two unsuccessful fusions in 1939 and 1940 A third fusion in 1942 was reported to be solid from the third lumbar vertebra to the sacrum She continued to have constant pain for several years and then intermittent symptoms for an additional period of time until we saw her in 1955 At surgery pseudarthroses were present at the third and fifth lumbar interspaces

An interesting study would be a long term follow up and search for pseudarthrosis in the apparently successful fusions for spondylolisthe sis by those medical centers where arthrodesis has long been the standard treatment for this condition By this study also more in formation could be gained about the secondary development of defects in the pars interarticularis of the vertebra above the fusion area In cidentally we have never seen such a defect occur following excision of the loose arch alone

ASSOCIATED DISC PATHOLOGY

Most patients with spondylolisthesis have degeneration of the fifth lumbar disc and usually the nuclear material is displaced anteriorly rather than posteriorly

In our fifty two cases one third of the patients had disc pathology which may have accounted for the onset of symptoms We found four herniations and ten protrusions of the fourth lumbar disc and at the fifth lumbar level we found one herniation and three protrusions In some of these cases the disc pathology rather than the spondylolisthesis appeared to be the sole cause of symptoms

Therefore the prevalent concept that onset of symptoms following injury in patients with spondylolisthesis merely represents an aggravation of a pre existing condition is no longer valid and in these cases serious consideration should always be given to the coexistence of disc pathology

REOPERATION FOLLOWING THE DECOMPRESSION PROCEDURE

a Unsuspected or Recurrent Disc Pathology

A herniation of the fourth lumbar disc was found in Case 40 at the time of the initial decompression Symptoms persisted and upon re exploration three months later a herniated disc was also found at the third lumbar interspace

In Case 42 discography two years postoperatively showed a new protrusion of the fourth lumbar disc and a protrusion of the third lumbar disc Symptoms however have not been sufficient to warrant re exploration and the patient continues to perform extremely heavy work

In those patients with involvement of the patellar reflex discography at the third lumbar interspace should be done prior to surgery

Case 36 was found to have a herniation of the fourth lumbar disc at the time of initial surgery He had a perfect result until he was involved in an automobile accident thirty four months postoperatively and again developed symptoms Re exploration revealed a reherniation of the fourth lumbar disc

Case 37 developed recurrence of symptoms one month after surgery as a result of a fall Seventeen months later a herniated disc was found and excised A reherniation at the same level occurred after numerous subsequent injuries and was removed thirty one months after the

initial surgery This patient often exhibits classical symptoms of conversion hysteria Although she is classified as a failure there are times when she gets along quite well

b Meningocele

Recurrence of local symptoms in the back and coccygeal area necessitated re exploration in two other patients in whom meningoceles were found

In Case 11 re exploration was performed nineteen months after the decompression operation and resulted in considerable relief of symptoms

In Case 49 the original decompression had been done elsewhere and had completely relieved symptoms for over five years Local back pain recurred however and upon re exploration seventy one months after the original surgery a very large meningocele was found and excised The patient developed a postoperative staphylococcal infection which resulted in a spinal fluid fistula This closed spontaneously after a period of bed rest in the head dependent position He returned to work four months after surgery and has been doing heavy welding work for the past three years without symptoms

It is probable that these meningoceles resulted from needle holes in the dura following myelography or discography At the time of surgery small dural defects should be sought and carefully closed with fine arterial silk

c Extraneural Scarring

Extraneural scarring may occur after surgery for spondylolisthesis as well as after any lumbar disc excision

Case 5 described previously developed left first sacral root findings nine and one half years after the orignal decompression Upon re exploration the first sacral root was found to be tented and bound down by scar and the root was released While being driven home from the hospital the patient was involved in an automobile accident she was thrown out on the road and the wound was torn open The wound healed nicely again but the patient has shown little if any improvement However there may understandably be a large element of psychic trauma as a result of this accident

Case 44 was re explored for scarring about the fifth lumbar root and

obtained some relief but this patient s symptoms are difficult to evaluate because of a coexistent severe plantar fascitis

Extraneural scarring may occur for several reasons Re exploration of patients after disc surgery has shown that incomplete excision of the ligamentum flavum results in its becoming bound down to the dura and emergent nerve roots For this reason there should be complete excision of ligamentum flavum from areas adjacent to the nerve roots

A second cause for scar formation results from the use of cottonoid as a packing and sponging material Reports of microscopic sections of extraneural scar frequently stated that suture material was present in the scar Since none had been used in the area it was obvious that the excessive scar was due to irritation from minute pieces of cotton oid For the last several years we have substituted polyvinyl sponge (*Ivalon*) in our cases This material is more resilient tougher than cottonoid and suction through it is superior to cottonoid

A third reason for extraneural scar we believe lies in the individual Patients with dark complexions tend to form excessive scar about the dural sac and emergent nerve roots This deep scar is almost always associated with visible keloid in the skin wound Patients with dark complexions have therefore been given deep x ray therapy beginning on the third postoperative day

d Intraneural Scar

Intraneural scar can exist prior to surgery as a result of prolonged root irritation and compression at the defect It can also be caused by undue trauma at the time of surgery These patients may have persistence of back and leg symptoms despite the presence of free straight leg raising It is our practice therefore to divide the sheath carefully if the root appears scarred at the time of surgery Neurolysis seems to give relief in about half of the cases attempted We find it impossible to predict however which patients may continue to have symptoms caused by intraneural scar formation

e Fusion after Arch Excision

Of the forty three patients treated initially by decompression we have subjected only two to attempted fusions later because of the persistence of symptoms following the decompression operation Interbody fusion was performed elsewhere in a third patient

The first patient (Case 21) had an attempted decompression operation elsewhere When we explored him eleven months later we found that the lateral portions of the arch and the cartilaginous mass had not been removed on either side and there was considerable scar formation about the roots Radicular pain continued after our decompression so five months later following discography which showed a protrusion of the fourth lumbar disc and marked degeneration of the fifth disc evacuation of these two disc spaces was attempted This procedure did not relieve symptoms either Therefore an *Adkins* fusion was attempted and resulted in fusion of the fourth to the fifth lumbar vertebrae but not of the fifth lumbar vertebra to the sacrum even though very little motion remained at this level The patient was improved by this procedure and was able to obtain a job as a swimming pool maintenance man Five years later he suddenly complained of an increase in sciatic pain and also had an episode of delirium tremens We refused to subject this man to further surgery but a month later another fusion operation was attempted elsewhere This too failed to relieve his symptoms We do not know whether solid fusion was obtained on the last occasion

The second patient (Case 41) had severe right sciatica and marked right fifth lumbar root findings At the initial surgery the fifth lumbar root was found to be impaled upon a spur arising from the right lateral portion of the loose lamina of the involved vertebra Relief of pain *followed the decompression However there was recurrence of severe* right leg pain and some back pain and nine months later an *Adkins* fusion was attempted The right leg pain was not relieved so after another nine month interval the sensory component of the right fifth lumbar root was divided under local anesthesia Symptoms were diminished for two years but the patient again returned because of low back and right leg pain The fusion was then reinforced over the facet area At surgery we found no motion between the fifth lumbar vertebra and the sacrum but some was evident between the fourth and fifth lumbar vertebrae This procedure did not relieve symptoms or result in fusion of the fourth to the fifth lumbar vertebrae One and one half years later we again explored the patient but were still unsuccessful in relieving her symptoms This woman is overweight and has been having severe personal difficulties and these factors may play some part in the persistence of her symptoms

Case 31 a cerebro spastic palsy victim with spastic paralysis of the lower extremities and a marked lumbar lordosis had the decompres

sion operation performed for low back and left sciatic pain Although she was improved moderately by the surgery the leg pain continued Four years later at a local clinic an anterior interbody fusion at the fourth and fifth lumbar levels was unsuccessful Three months later a re exploration also failed to relieve her symptoms After these two operations the patient was confined to a wheel chair We re explored the site of the decompression a year later Considerable scar was re sected and the patient was placed on an active postoperative course of exercises and swimming She returned to college was ambulatory without crutches and was able to carry out the activities which she had been incapable of performing following the attempted fusion

Our experience with the fusion operation for various types of low back conditions indicates that it will not relieve radicular pain

OTHER COMPLICATIONS OF SURGERY

a Wound Infections

Wound infections occurred in two patients (Cases 40 and 49) but fortunately did not adversely affect the final results

b Thrombophlebitis and Pulmonary Embolism

One case of thrombophlebitis occurred in this series (Case 3) This patient had a conventional fusion operation in 1949 and developed a thrombophlebitis during the postoperative period She continues to have some swelling of the involved leg

Case 1 who initially had a combined decompression and fusion operation developed a mild pulmonary embolism after a secondary decompression operation was done for removal of bony fragments which had sunk in on the dural sac

In general however our entire series of cases seems to be singularly free from the complications of thrombophlebitis or pulmonary em bolism and we believe this is because of the early exercise and ambu lation permitted by the decompression procedure

c Poor Patient Selection

Poor patient selection is another cause of poor results after any operative procedure In this series we have four patients who show definite evidence of conversion hysteria (Cases 30 33 37 and 41) Two other patients were extremely neurotic and one we learned later was

a chronic alcoholic If any overt emotional problems are apparent in a patient we do not believe that he is a candidate for any type of back surgery

We also feel that this procedure should be used with caution in patients who have litigation pending For example Case 33 who was noted above to have a conversion hysteria had an industrial injury and claimed no improvement after surgery although there were no positive findings at the time we last saw him Three other patients however were involved in accidents and subsequent litigation and all showed prompt relief of symptoms following surgical treatment (Cases 11 16 and 36)

RESULTS

Our cases were analyzed according to *Barr s* criteria except that those cases which required reoperation were not automatically considered failures This change was necessary in all fairness because many of our patients sustained injuries after surgery and because excellent results by the fusion method are reported in many papers but two or more operations were often necessary to achieve the reported results

a Initial Decompression

Of the forty three cases of initial decompression 86 1 per cent are considered satisfactory and 13 9 per cent unsatisfactory Eighteen or 41 8 per cent are asymptomatic twelve or 28 per cent are good seven or 16 3 per cent are fair and six or 13 9 per cent are failures If one considers only the twenty four cases in this group who have been followed over five years the results are very little different twelve or 50 per cent are asymptomatic four or 16 7 per cent are good three or 12 5 per cent are fair and five or 20 8 per cent are failures

b Combined Arch Excision and Fusion

In our group there were only two patients who had combined arch excision and fusion as one operative procedure The first (Case 1) did well for a period of time but then developed a pseudarthrosis and recurrence of symptoms She was markedly improved following a second decompression procedure but was finally lost from further follow up She was considered to have a fair result

The second patient (Case 2) developed recurrence of back and leg pain soon after the initial surgery Re exploration showed that the grafts had slipped medially causing irritation and pressure on the lower dural sac and necessitating removal of the bony material Re fusion with rib grafts was attempted but although solid fusion was obtained it did not result in complete relief of symptoms However the patient does quite well at this time and is considered to have a fair result

c Decompression after Previously Attempted Fusion

The six remaining patients in this series were treated by the decom pression operation after attempted fusion had failed to relieve their symptoms One is considered to have a good result four patients are classified as fair and one is a failure

Case 18 had three unsuccessful fusions and was finally advised to seek psychiatric care before we first saw her While under our care she has had four additional operations the last over three years ago when a new protrusion of the fifth lumbar disc was removed She has a fair result but feels much better and now is able to participate in sports such as water skiing and bowling She also holds a full time job in addition to doing her housework and caring for her two children

Case 27 had three fusion operations was able to work for fifteen years and then became completely disabled Following the decom pression she has been able again to do her regular work and is listed as a fair result

Case 30 shows evidence of a classical conversion hysteria but actual ly has a fair result following the decompression operation

Case 9 a good result and Case 25 a fair result were improved after the decompression but have been lost from further follow up Case 17 was classified as a failure on the basis of her complaints although all physical neurological and x ray examinations were normal

Although our results in this group of cases are not striking they do illustrate that patients who are completely disabled following attempted fusion operations can be rehabilitated by the decompression procedure

CONCLUSIONS

Our experiences gained from treating symptomatic spondylolisthesis by the techniques which we have developed over the past thirteen years are briefly summarized as follows

1 These patients should first be treated with an active exercise pro

gram consisting of straight leg raising and sitting toe touching exercises The use of a brace or any type of support has usually only aggravated symptoms

2 Surgery is considered necessary in those patients who despite the treatment outlined above continue to have severe symptoms or in those who are prevented from enjoying normal lives because of recurrent episodes of disability

3 From our limited experience it appears that the decompression operation may also be used in children whose symptoms are persistent and severe In those who show the progressive displacement criteria of *Taillard* treatment should only be undertaken after a thorough discussion with the parents regarding the probability of further forward displacement

4 Anterior displacement of varying degrees occurs in a few adults after the decompression operation This begins as a narrowing of the disc below the involved vertebra is limited and does not necessarily lead to onset of symptoms The same percentage of men and women showed postoperative progression of displacement but a greater degree of displacement occurred in women Most of the women were within the child bearing age and three had from one to three children following the decompression operation In our opinion removal of the arch neither causes further forward displacement nor influences its amount

5 Aside from the usual degenerative changes at the fifth lumbar disc disc protrusion or herniation at other levels is present in one third of the cases It most commonly occurs at the interspace above the spondylolisthetic vertebra where the greatest stress is placed because of the small amount of motion present between the involved vertebra and the one below

6 Results of the decompression operation we feel are satisfactory under the following conditions

a The procedure must be performed thoroughly by complete removal of the arch and decompression of the involved roots past the pedicles

b Disc pathology should be recognized and dealt with at the time of surgery

c The postoperative care must consist of the prompt initiation of straight leg raising exercises and later toe touching exercises in order to insure free nerve root excursion Complications such as thrombophlebitis and pulmonary emboli will also thus be avoided

7 If patients develop recurrence of symptoms following surgery one should not hesitate to reoperate after employing the usual diagnostic methods of thorough neurological examination plus myelography and/or discography

8 In our experience attempts at fusion after arch excision because of persistent radicular symptoms will not relieve pain arising from nerve root involvement In addition fusion is difficult to achieve

TABLE

Synopsis of Cases of Spondylolisthesis Originally Treated

Case	Sex	Age	Occupation	Onset with injury	Duration of symptoms	Length of conservative treatment
4	M	41	Physician	No	5 years	5 years
5	F	30	Housewife	No	5 years	4 years
6	M	37	Salesman	No	2 years	18 months
7	F	23	Housewife and secretary	No	2 weeks	None
8	M	37	Laundryman	No	9 years	9 years
10	F	44	Housewife	No	14 years	10 years
11	F	27	Secretary	Yes	16 months	16 months
12	F	27	Housewife	No	4 years	1 year
13	M	35	Floor covering contractor	Yes	Many years worse last 15 months	4 months
14	M	19	Clerk and laborer	Yes	4 months	1 month
15	F	24	Housewife	No	2 years	18 months
16	F	25	Clerk and housewife	Yes	7 months	7 months
19	M	23	Medical student	No	Several years	10 months
20	M	40	Teamster	No	2 years	1 year
21	M	32	Carpenter	No	2 years	2 years
22	M	52	Marine electrician	No	All of life worse last 7 years	7 years
23	F	41	Clerk	Yes	9 months	9 months
24	M	51	Janitor	Yes	24 months	24 months
26	F	47	Bookkeeper	Yes	Many years worse last 2 months	2 months

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L lan l d gr of l spl c n nt	A t lan m l	D gr of p op t e d sabil t
Lumbar 5 first	Upper lumbar curve left	Total
Lumbar 5 first	Mild thoraco lumbar curve left	Total
Lumbar 5 first	Bifid lamina lumbar 5 with fusion to spinous process of sacral 1 Spina bifida occulta of sacral 1	Total
Lumbar 5 first	Upper lumbar curve right	Total
Lumbar 5 first	Spina bifida occulta sacral 1	Total
Lumbar 5 first	None	Moderate
Lumbar 5 first	Thoraco lumbar scoliosis left	Total
Lumbar 5 first	Bifid lamina lumbar 5 Spina bifida occulta sacral 1	Total
Lumbar 5 first	Spina bifida occulta sacral 1 with fusion spinous processes lumbar 5 and sacral 1	Total
Lumbar 5 first	None	Moderate
Lumbar 5 second	None	Total
Lumbar 5 first	Mild upper lumbar curve left	Total
Lumbar 5 first	Spina bifida occulta sacral 1	Total
Lumbar 5 first	Lumbar curve right	Moderate
Lumbar 5 first	Upper lumbar curve left	Total
Lumbar 4 first	Reverse" spondvlolisthesis lumbar 5	Total
Lumbar a spondvlolvsis	Unilateral defect lumbar 5 left Bifid lamina lumbar 5	Total
Lumbar 5 first	Spina bifida occulta sacral 1 with fusion spinous processes lumbar 5 and sacral 1 Healing of defect lumbar 5 right found at surgery	Total
Lumbar 5 first	Mild right thoraco lumbar curve	Total

TABLE

Case	Sex	Age	Occupation	Onset with injury	Duration of symptoms	Length of conservative treatment
28	F	38	Bookkeeper and housewife	No	16 years	11 years
29	F	47	Shipping clerk and housewife	No	4 5 years	4 years
31	F	21	Student	Yes	5 years	11 months
32	M	51	Janitor	No	10 months	10 months
33	M	49	Painter	Yes	1 year	1 year
34	M	37	Grocery clerk	Yes	1 month	1 month
35	M	36	Teacher	No	2 5 years	5 months
36	M	38	Truck driver	Yes	1 year	8 months
37	F	40	Waitress and housewife	No	3 years	1 year
38	F	38	Waitress	Yes	20 years	Several years
39	M	45	Banker	Yes	Several years	8 months
40	F	36	Housewife and magazine sales	Yes	1 year	4 months
41	F	30	Maid and housewife	Yes	3 years	3 years
42	M	47	Construction worker	No	5 years	4 5 years
43	F	57	Assembly worker	No	9 weeks	5 weeks
44	F	55	Housewife	No	14 years	13 years
45	F	57	Housewife	No	5 years	4 years

—4 (cont)

Level and degree of displacement	Additional anomalies	Degree of preoperative disability
umbar 5 fourth	Fusion of facets lumbar 5 to sacrum found at surgery	Total
umbar 5 first	Spina bifida occulta sacral 1	Moderate
umbar 5 first	Cerebro-spastic palsy	Questionable because of palsy
umbar 5 first	None	Total
umbar 5 spondylolysis	None	Questionable
umbar 5 first	Mild thoraco lumbar curve left Fusion spinous processes lumbar 5 and sacral 1	Total
umbar 5 first	Bifid lamina lumbar 5	Total
umbar 5 first	Mild mid lumbar curve left Bifid lamina lumbar 5 Spina bifida occulta sacral 1	Total
umbar 5 first	Porphyrinuria diagnosed after surgery	Total
umbar 5 first	Right lumbar left thoracic scoliosis	Total
umbar 5 first	Mild left lumbar curve Bifid lamina lumbar 5 *Spina bifida occulta sacral 1*	Total
umbar 5 first	Left thoraco lumbar scoliosis Sustained compression fractures of thoracic 9 and lumbar 1 65 months after initial surgery	Total
Lumbar 5 first	Slight left upper lumbar curve Spike of bone down from right lamina of lumbar 5 to nerve root found at surgery	Total
Lumbar 5 first	Right thoraco lumbar scoliosis Fusion inferior facet lumbar 5 to superior facet sacral 1 left and bilateral healing of defect lumbar 5 found at surgery	Total
Lumbar 5 first	Right lower thoracic curve	Total
Lumbar 5 first	Right mid thoracic curve Chronic plantar fasciitis Negative for rheumatoid arthritis	Moderate
Lumbar 5 first	Right mid thoracic left low thoracic curve mild	Total

TABLE

Case	Sex	Age	Occupation	Onset with Injury	Duration of symptoms	Length of conservative treatment
46	F	29	Brushmaker and housewife	No	7 years worse last 10 months	10 months
47	M	57	Automobile painter	Yes	6 5 years	6 years
48	F	46	Housewife	Yes	8 years worse last 1 year	8 years
49	M	48	Welder	No	10 months	9 months
50	F	14	Student	Yes	4 years	28 months
51	M	14	Student	No	27 months	26 months
52	M	52	Farmer	Yes	Many years worse last 6 weeks	6 weeks

Total = Unable to carry out any activities Severe back and (or) lower extremity pain
Moderate = Unable to carry out most activities Moderate back and (or) lower extremity pain
Mild = Able to carry out most activities Mild pain in back or lower extremities

1—A (cont.)

Level and degree of displacement	Associated anomalies	Degree of preoperative disability
Lumbar 5 first	None	Total
Lumbar 5 first	Spina bifida occulta sacral 1 Fusion spinous processes lumbar 5 and sacral 1	Total
Lumbar 5 first	None	Total
Lumbar 4 first	Mild left mid lumbar curve	Total
Lumbar 5 first	Left lumbar curve Spina bifida occulta sacral 1	Total
Lumbar 5 fourth	Osteochondritis Mild left lumbar curve Progression of forward displacement from second to nominal fourth degree allowed to occur before surgery	Total
Lumbar 4 first	Right upper lumbar curve Transitional fifth lumbar vertebra	Total

TABLE

Comparison of Symptoms and

Case	Back pa n	Area of rad cular pa n	Abnormal physic l findings	Nerve r ots involved
			P ope ati	
4	Moderate	Left sciatica severe	Flexion 18 in of floor SLR 80 right 3 left	Lumbar 5 sacral 1 left moderate
5	Moderate	Calves severe	Extension restricted and painful	Lumbar 5 left moderate
6	Mild	Buttocks Left sciatica severe	Flexion 6 in of floor Extension restricted and painful SLR 80 right 60 left	Lumbar 5 sacral 1 left moderate
7	Moderate	Buttocks severe	Flexion 4 in of floor Extension restricted and painful	Lumbar 5 right moderate
8	Severe	Right buttock severe	Flexion 18 in of floor Right list Extension restricted and painful SLR 10 right 60 left	Lumbar 5 sacral 1 right moderate
10	Moderate	Coccyx and right sciatica moderate	Extension restricted and painful SLR 60 right 90 left	Lumbar 5 sacral 1 right moderate
11	Mild	Left sciatica severe	Flexion 10 in of floor Extension restricted and painful	Lumbar 5 sacral 1 left moderate
1?	Severe	Left sciatica severe	Extension restricted and caused increase in radicular pain and neurological findings	Lumbar 5 left moderate
13	Severe	Right buttock and sciatica moderate	Extension restricted and caused increase in radicular pain and neurological findings	Right lumbar 5 moderate sacral 1 mild
14	Moderate	Sciatica moderate Right buttock	Extension restricted and caused increase in radicular pain and neurological findings	Lumbar 5 bilateral moderate Sacral 1 right mild
15	Severe	Posterior thighs severe	Flexion 18 in of floor SLR 80 right ?0 left Extension re stricted and painful	Lumbar 5 bilateral severe Sacral 1 right moderate

I—B
Findings before and after Surgery

	Postop rat ve (most nt exam tion)		
Ba k p n	A of ra I cula pain	Ab m I physical f nd ngs and ma k	Nerv roots in ol ed
Occasional ache	Occasional left sciatica	Carries out full practice includ ing long periods in surgery daily	Lumbar 5 sacral 1 mild
Occasional ache	Occasional left sciatica	Touches floor 2 pregnancies postoperatively Reoperated See Table 1—D	Sacral 1 left
None	Occasional right calf mild	Flexion to 4 in of floor Exami nation negative	None
None	None	3 pregnancies postoperatively Examination negative	None
None	None	Flexion to 3 in of floor Exami nation negative	None
Occasional mild	None	Flexion 2 in of floor Examina tion negative	None
None	Right thigh and buttock, moderate	Flexion 12 in of floor SLR 60 right 75 left Reoperated See Table 1—D	None
None	None	Touches floor Examination negative	None
None	None	Acute flare up 8 5 years after surgery Findings indicated pos sible disc protrusion Subsided in 1 week Again asymptomatic and examination negative	None
None	None	Examination negative except for recent right peroneal palsy caused by habit of sitting with right leg crossed over left during prolonged periods of studying	None other than right peroneal pal y
Occasional catching	Occasional left calf ache	Touches floor	Lumbar 5 left mild

TABLE

Preoperative				
Case	Back pain	Area of radicular pain	Abnormal physical findings	Nerve roots involved
16	Moderate	Lateral right calf severe	Extension restricted and painful	Lumbar 5 right moderate
19	Mild	Sciatica right severe	Flexion 2 in of floor SLR 60 right 80 left	Sacral 1 right moderate
20	Moderate	Left buttock moderate	None	Lumbar 4 and 5 left mild
21	Severe	Sciatica bilateral moderate	Extension restricted and painful and caused increase in radicular pain and neurological findings	Lumbar 5 bilateral sacral 1 right moderate
22	Severe	Severe right sciatica	Moderate spasm Flexion 15 in of floor SLR 60 right 70 left	Lumbar 4 and 5 bilateral moderate
23	Mild	Severe right sciatica	Extension restricted and painful Slight spasm SLR 60 right	Lumbar 5 sacral 1 bilateral moderate left severe right
24	Only on hyper extension severe	Left sciatica severe	Flexion 7 in of floor SLR free but painful Extension reproduced left sciatic pain	Lumbar 5 bilateral worse on left Left sacral 1 severe
26	Severe	Inner thighs moderate	Two stage recovery from flexed position Spasm	Lumbar 5 right moderate
28	Severe	Posterior thighs and calves severe	Flexion 6 in of floor SLR free Extension painful Unexplained urinary incontinence	Lumbar 5 sacral 1 bilateral severe
29	Moderate	Bilateral sciatica moderate	Flexion free Pain on extension	Lumbar 5 right moderate Sacral 1 left mild

1—B (cont)

Postoperative (most recent examination)			
Back pain	Area of radicular pain	Abnormal physical findings and remarks	Nerve roots involved
None	None	Touches metacarpal heads to floor Examination negative 3 pregnancies postoperatively	None
None	None	Flexion 4 in of floor SLR 80 bilaterally	None
None	None	Touches floor Examination negative	None
Occasional severe	Occasional left great toe severe	No abnormal clinical findings Neurologic examination shows objective left sacral 1 findings but only subjective left lumbar 5 findings Reoperated See Table 1—D	Sacral 1 left
None	None	Flexion 6 in of floor Examination negative	None
Stiffness	Cramping in calves worse on right	Flexion 1 in of floor SLR 90 bilaterally	Bilateral lumbar 5 sacral 1 mild
Rare catch of pain	None	Touches floor Extension slightly restricted	None
Moderate	None	Examination negative Touches floor	None
None	None	Urinary incontinence disappeared	Bilateral lumbar 5 mild
None	Very mild buttock pain on right	Flexion to hands flat on floor Examination negative	None

TABL

Preoperative				
Case	Back pain	Area of radicular pain	Abnormal physical findings	Nerve roots involved
31	Severe	Sciatica left severe	Flexion only to knees due to spasticity Neurological evaluation difficult because considerable paralysis	Lumbar 5 left suggestive
32	Severe	Coccyx severe both legs to heels worse on left	Flexion 16 in of floor Little lumbar motion SLR 70 right with leg pain and 50 left with back pain	Sacral 1 left
33	Constant dull ache	Constant in right lateral thigh	Industrial injury Slight left list Flexion 2 in of floor No spasm or two stage recovery Compromise and release recommended initially on basis of definite exaggeration of complaints	Lumbar 5 righ mild
34	Severe	Right sciatica moderate	Right list Back motions restricted and painful SLR 60 right positive Lasegue SLR 80 left	Lumbar 5 bilateral moderate worse on right
35	Moderate	Left calf severe Right leg intermittent	Flexion to 8 in of floor SLR 70 bilaterally	Lumbar 5 lef moderate
36	Left moderate	Left sciatica severe	Left list Deviation to left on flexion SLR 80 right with pain left back SLR 45 left	Lumbar 4 sacral 1 left mild
37	Severe	Right sciatica severe	Flexion mid way between knees and ankles SLR 45 right 90 left	Lumbar 5 sacral 1 right moderate
38	Severe	Right thigh	Extension restricted and painful SLR tight bilaterally and painful on right	Sacral 1 right mild
39	Severe	Both buttocks Both legs	Rigid back Flexion to knees Right list SLR 80 right Tender over loose arch	Lumbar 5 righ moderate

1—B (cont)

Postoperative (most recent examination)			
Back pain	Area of radicular pain	Abnormal physical findings and remarks	Nerve roots involved
Moderate	Left leg moderate	SLR free Touches toes No two stage recovery from flexion Reoperated See Table 1—D	Difficult to evaluate
None	None	Flexion to 3 in of floor Examination negative	None
Morning stiffness	Left sciatica	Camptocormia Stocking hypesthesia entire right lower extremity and left leg below knee Normal back motion SLR past 90 bilaterally Only positive finding was right heel jerk depression	Sacral 1 right mild
Tired feeling with over activity only	Some tenderness dorsum of right foot	Touches floor Slight left list which increases with fatigue but is not associated with any pain SLR 85 right 90 left	Lumbar 5 right mild
None	None	Touches floor Examination negative	None
None	None	Touches floor Had re injury after surgery See Table 1—D Completely asymptomatic and doing everything	None
Constant Varies in degree and location	Both legs intermittent worse on right	SLR slightly restricted and causes back and leg pain Flexion good from sitting position Atrophy of 0 25 in right calf 1 in left thigh	Lumbar 4 right and lumbar 5 bilateral mild
None	None	Flexion to palms flat on floor Examination negative	None
None	None	Clinical examination negative Only neurologic finding is slight depression both heel jerks	Sacral 1 bilateral slight

		Preoperati e		
Ca e	Back pain	A a of ra licular pain	Abnormal physical fin lings	Nerve roots in ol ed
40	Severe	Coccyx left buttock entire right leg severe	Left list Flexion and right bend restricted and painful SLR 70 right with pain SLR 90 left with tightness	Lumbar 5 right moderate
41	Severe	Severe right sciatica into all toes	Rigid back Unable to straighten up SLR 15 right 45 left Loss of dorsiflexor power right foot	Lumbar 5 right severe
42	Severe	Both hips and legs worse on right	Flexion restricted and painful SLR 70 right 80 left	Lumbar 5 bilateral moderate worse on right
43	Severe	Right hip thigh and ankle moderate	Acute tenderness right sciatic notch Flexion caused right leg pain SLR 80 right	Lumbar 5 right severe
44	Moderate	Right thigh moderate	Flexion to 4 in of floor SLR 70 bilaterally	Lumbar 5 right moderate
45	Moderate	Left sciatica into great toe severe	Good back motions SLR free	Lumbar 5 left moderate
46	Moderate	Left leg severe Right leg mild	Flexion to 6 in of floor SLR tight Tender over loose arch	Lumbar 5 sacral 1 right moderate
47	Severe	Left calf severe	Back motions restricted SLR 70 left	Lumbar 5 sacral 1 left

1—B (cont.)

Postoperative status (most recent examination)			
Back pain	Area of radicular pain	Abnormal physical findings and remarks	Nerve roots involved
None	Right calf mild	No low back discomfort Some pain over fracture site above Touches floor Numerous re injuries Reoperation See Table 1—D	None
Intermittent ache varying intensity	Persistent severe right sciatica	Prompt return lumbar 5 right nerve function Flexion 12 in of floor Severe home problems Nail biter Reoperated See Table 1—D	None
Mild Occasional	Right leg mild	Flexion to 3 in of floor Some discomfort on extension Works 15 hrs per day on maintenance heavy highway equipment Back discomfort on lifting more than 150 pounds	Lumbar 5 sacral 1 left mild
None	None	Slight tenderness right sciatic notch Abdominal discomfort SLR free Symptoms probably due to coexistent arteriosclerotic vascular disease	None
Constant Moderate	Right calf mild	Touches floor but complains of pain on bending Acute plantar fasciitis Reoperated See Table 1—D	Sacral 1 bilateral mild
None	Right buttock occasionally	Asymptomatic until a fall 2 years after surgery Now has some pain on hyperextension Right buttock pain only after prolonged inactivity	None
Mild ache	None	Flexion to 6 in of floor Had re injury	None
Stiffness only	Both legs mild	Only symptom was slight back stiffness after long inactivity until injured in auto accident 15 months after surgery Recent x ray evidence of increased spurring at lumbar 3 disc	None

TABLE

Cas	Back pain	Area of ra l cular pain	Preoperative Al normal physical fin lings	Nerve roots involved
48	Aching severe	Both thighs intermittent severe	Good back motions SLR 70 bilaterally with pain Tender over loose arch	Lumbar 5 bilateral mild Sacral 1 left moderate
49	Severe	Left buttock and posterior thigh both calves	Initial decompression elsewhere Previous examiner reported spasm restriction all back mo tions and SLR 50 bilaterally See Table 1—D	None reported
50	Severe	Both legs to heels worse on right	Extension painful SLR 50 right 85 left	Lumbar 5 sacral 1 right
51	Severe only pre sent on jarring motions	Both legs worse on left present only after pro longed walking	Marked lordosis Flexion re stricted and caused leg pain bilaterally Unable to walk on toes of left foot	Lumbar 5 bilateral worse on left Sacral 1 left mild
5?	Severe	Both legs severe	Marked left list Marked re striction SLR with pain Rigid back	Lumbar 4 sacral 1 bilateral lumbar 5 left

SLR = Straight leg raising

1-B (cont)

Postoperative (most recent e amin tion)			
Ba k p in	Ar a of rad cul r pa n	Abnormal pl ysi al findi g nd r ma k	Nerv oots invol d
None	None	Completely negative in all respects	None
None	None	Flexion to 1 in of floor Asymptomatic	Lumbar 5 left mild
None	None	Flexion to 4 in of floor Examination negative Asymptomatic	None
Occasional mild	None	Injured in auto accident 15 months after surgery Had recurrence of symptoms and findings Subsided in 1 month Some back pain now when working long hours under his car	Lumba 5 right mild
None	Right thigh mild	Flexion 4 in of floor	Lumbar 4 bilateral

TABLE

Correlation of Surgical Findings with

Case	Preoperative neurological findings	Surgical	
	Nerve roots involved	Mobility of free lamina	Fibrocartilaginous mass
4	Lumbar 5 sacral 1 left moderate	Marked	Bilateral
5	Lumbar 5 left moderate	Moderate	Bilateral larger on left
6	Lumbar 5 sacral 1 left moderate	Marked	Bilateral larger on left
7	Lumbar 5 right moderate	Marked	Bilateral larger on right
8	Lumbar 5 sacral 1 right moderate	Marked	Bilateral larger on right
10	Lumbar 5 sacral 1 right moderate	Marked	Bilateral larger on right
11	Lumbar 5 sacral 1 left moderate	Marked	Bilateral larger on left
12	Lumbar 5 left moderate	Marked	Bilateral larger on left
13	Right lumbar 5 moderate sacral 1 mild	Marked	Bilateral larger on right
14	Lumbar 5 bilateral moderate Sacral 1 right mild	Marked	Bilateral
15	Lumbar 5 bilateral severe Sacral 1 right moderate	Slight	Bilateral larger on right
16	Lumbar 5 right moderate	Marked	Bilateral
19	Sacral 1 right moderate	Marked	Bilateral larger on right
20	Lumbar 4 and 5 left mild	Slight	Bilateral larger on left
21	Lumbar 5 bilateral sacral 1 right moderate	Marked	Bilateral larger on left
22	Lumbar 4 and 5 bilateral moderate	Slight	Bilateral larger on right
23	Lumbar 5 sacral 1 moderate left severe right	None right but marked left	(Unilateral defect) Left small
24	Lumbar 5 bilateral worse left Sacral 1 left severe	None	Left small and posterior

1—C
Preoperative \eurological Findings

f n l n rs

Loo e os t le at t of ps u l th o	D se patholo
Left	\one
\one	\one
\one	Protrusion lumbar 4 left
Left	\one
\one	Protrusion lumbar 4 right
\one	\one
\one	\one
\one	\one
\one	\one
\one	\one
\one	\one
\one	\one
\one	\one
\one	\one
Left	Questionable Disc material not removed
Bilateral	\one
\one	Herniation lumbar 4 right
P eudarthrosis healed on right I se ossicle pre ent on right	\one

TABLE

Case	Preoperative neurological findings	Surgical	
	Nerve roots involved	Mobility of free lamina	Fibro cartilaginous mass
26	Lumbar 5 right moderate	Moderate	Bilateral
28	Lumbar 5 sacral 1 bilateral severe	None	Bilateral marked
29	Lumbar 5 right moderate Sacral 1 left mild	Moderate	Bilateral
31	Lumbar 5 left suggestive	None	Bilateral moderate
32	Sacral 1 left	Marked	Bilateral more on right but not compressing roots
33	Lumbar 5 right mild	Moderate	Bilateral compressing root on right
34	Lumbar 5 bilateral worse on right	Moderate	Bilateral compressing both lumbar 5 roots
35	Lumbar 5 left moderate	Marked	Bilateral larger on left
36	Lumbar 4 and sacral 1 left mild	Marked	Bilateral moderate
37	Lumbar 5 sacral 1 right moderate	Marked	Bilateral larger on right
38	Sacral 1 right mild	Moderate	Bilateral small not compressing roots
39	Lumbar 5 right moderate	Marked	Bilateral not compressing roots
40	Lumbar 5 right moderate	Marked	Bilateral
41	Lumbar 5 right severe	Moderate	Bilateral
42	Lumbar 5 bilateral worse on right	None	None Defects healed bilaterally

1—C (cont)

f n l ngs

Lo s 1 t ue of p u l rthrosis	Disc p thology
None	Lumbar 4 soft and soggy but not bulging Material excised
Right Spontaneous fusion of lumbar 5 inferior facets to sacrum	None
None	None
None	None
No loose ossicle but considerable pile up of bone at defect on right	Protrusion lumbar 5 with adherence of sacral 1 root left
No loose ossicle Spur near sacral 1 root right removed to avoid cause for future symptoms	Mild protrusion lumbar 4 Excised
None	None
None	None
None	Protrusion lumbar 4 left
No loose ossicle Lumbar 5 root right compressed by spur	None
None	Protrusion lumbar 4 and 5 left
Left	Herniation lumbar 4 right with right lumbar 5 root bound down to it
None	Complete herniation nucleus of lumbar 4 with fragments bilaterally slightl away from the midline
No loose ossicle Sharp spur down from lamina of lumbar 5 directly impaled right fifth root	Lumbar 4 soft and protruded in midline Annulus of lumbar 5 tight
No loose o si les Build up of bone at healed defects ompressed both lumbar 5 roots wor on right Spontaneous fusion lumbar 5 and sacral 1 facets left	None at this surgery Discogram 20 months later showed degeneration lumbar 3 disc and posterior herniation lumbar 4

TABLE

Case	Preoperative neurological findings	Surgical	
	Nerve roots involved	Mobility of free lamina	Fibrocartilaginous mass
43	Lumbar 5 right severe	Moderate	Bilateral not compressing roots
44	Lumbar 5 right moderate	Slight	Bilateral
45	Lumbar 5 left moderate	Marked	Bilateral very large on right
46	Lumbar 5 and sacral 1 right moderate	Marked	Bilateral small
47	Lumbar 5 and sacral 1 left	Marked	Marked on left None on right
48	Lumbar 5 bilateral mild Sacral 1 left moderate	Moderate	Bilateral small
49	None reported	Marked	Bilateral
50	Lumbar 5 and sacral 1 right	None	None No defects demonstrable Dural sac compressed by tight lamina of lumbar 5 Lamina of lumbar 5 excised but inferior facets left intact
51	Lumbar 5 bilateral worse on left Sacral 1 left mild	None	Bilateral small not compressing roots
52	Lumbar 4 and sacral 1 bilateral Lumbar 5 left	Marked	Bilateral

1—C (cont)

f d n s	
Loo o st le at s t of ps u la lt ro	D e p thology
None	Herniation lumbar 4 right from which material had traveled downward about 7 mm Lumbar 5 disc normal
None	Bilateral protrusion lumbar 4
None	Protrusion lumbar 4 left
No loose ossicle Large pile up of bone at defect on right	Lumbar 4 soft but not protruding
None	Protrusion lumbar 5 right
None	Herniation lumbar 5 left Mild protrusion lumbar 4 right
None	None
None	None
No loose ossicle Right lumbar 5 root adherent at hop off between lumbar 5 and sacral 1 Solid fusion of facets lumbar 5 to sacrum	None
Right	Herniation lumbar 4 right

TABLE 1—D
Reoperation

Case	Months after decompression	Indications for reoperation	Operation and surgical findings	Results and remarks
9	115	Back discomfort and left sciatica returned when lying in bed Loss of left ankle jerk	Exploration Kinking left sacral 1 root by scar Bony over growth inferior facet lumbar 4 left	Thrown from car ninth postoperative day Wound torn open Sutured Healed per primam Nervous since Improvement moderate only
11	19	Developed coccygeal and right buttock pain SLR 70 right Left ankle jerk depressed	Exploration Meningocele 2 × 2 mm in size removed External neurolysis Marked scar about right lumbar 5 root	Flexion to level of knees Some pain behind right knee No back pain Good result
21	1 11	1 Initial excision of arch elsewhere incomplete Catching pain in back	1 Excision of fragments of loose lamina External neurolysis sacral 1 root left	1 Recurrent catching pain in back with associated clicking feeling and noise
	2 15	2 Catching in back Left sacral 1 findings	2 Excision degenerated lumbar 4 disc Adherent lumbar 5 root left	2 Improved
	3 39	3 Persistent back and left leg pain Sacral 1 findings left	3 No abnormal findings *Adhesions* fusion lumbar 4 to sacrum attempted	3 Marked improvement but continued to have some left leg pain
	4 99	4 Back pain and left leg radiation 5 in atrophy left calf Left heel jerk depressed	4 Done elsewhere Fusion not solid between lumbar 5 and sacrum	4 Mild sacral 1 findings and left lumbar 5 pain

31	1	48	1 Done elsewhere for back and left leg pain	1 Anterior interbody fusion lumbar 4 and 5	1 Failure of fusion
	2	2	2 Done elsewhere for back and left leg pain	2 Re exploration of lumbosacral area	2 Failure Patient now confined to wheel chair after this procedure
	3	63	3 Inability to carry out many former activities because of wheel chair confinement Marked restriction SLR bilaterally Persistent back pain and stiffness	3 Exploration laminectomy wound Excision of considerable scar about dural sac and nerve roots	3 Patient again ambulatory without crutches and back in college Able to swim Marked improvement in back and leg pain back motions and SLR Difficult to evaluate neurologically because of the considerable spastic paralysis of lower extremities
36		32	Re injury to back in rear end auto collision 32 months after surgery Developed pain left low back and left thigh numbness left foot and some left calf atrophy No improvement after exercise program	Excision of reherniated lumbar 4 disc left and some scar about the root	Last seen 78 months after original surgery Asymptomatic Neurologically negative
37	1	18	1 1 month after surgery had a fall Restriction SLR and flexion Lumbar 5 neurologic findings right Discogram 17 months later showed herniation lumbar 4 disc	1 Excision of a central protrusion lumbar 4 disc	1 Improved
	2	31	2 23 months after initial surgery had second injury Limitation SLR and back motion Stocking hypesthesia right leg Numerous other injuries	2 Excision of reherniated lumbar 4 disc right Lumbar 5 and sacral 1 roots bound down by scar	2 Failure Left leg pain SLR 75 right 70 left with back pain Stocking hypesthesia right leg Porphyrinuria diagnosed Conversion hysteria Attempted suicide Under psychiatric care

TABLE 1—D
Reoperation

Case	Months after decompression	Indications for reoperation	Operation and surgical findings	Result and remarks
[illegible]	115	Back discomfort and left sciatica returned when lying in bed Loss of left ankle jerk	Exploration Kinking left sacral 1 root by scar Bony over growth inferior facet lumbar 4 left	Thrown from car ninth postoperative day Wound torn open Sutured Healed per primam Nervous since Improvement moderate only
11	19	Developed coccygeal and right buttock pain SLR 70 right Left ankle jerk depressed	Exploration Meningocele 2 × 2 mm in size removed External neurolysis Marked scar about right lumbar 5 root	Flexion to level of knees Some pain behind right knee No back pain Good result
21	1 11	1 Initial excision of arch elsewhere incomplete Catching pain in back	1 Excision of fragments of loose lamina External neurolysis sacral 1 root left	1 Recurrent catching pain in back with associated clicking feeling and noise
	2 15	2 Catching in back Left sacral 1 findings	2 Excision degenerated lumbar 4 disc Adherent lumbar 5 root left	2 Improved
	3 39	3 Persistent back and left leg pain Sacral 1 findings left	3 No abnormal findings *Adkins* fusion lumbar 4 to sacrum attempted	3 Marked improvement but continued to have some left leg pain
	4 90	4 Back pain and left leg radiation 5 in atrophy left calf Left heel jerk depressed	4 Done elsewhere Fusion not solid between lumbar 5 and sacrum	4 Mild sacral 1 findings and left lumbar 5 pain

31	1	48	1 Done elsewhere for back and left leg pain	1 Anterior interbody fusion lumbar 4 and 5	1 Failure of fusion
	2	52	2 Done elsewhere for back and left leg pain	2 Re exploration of lumbosacral area	2 Failure Patient now confined to wheel chair after this procedure
	3	53	3 Inability to carry out many former activities because of wheel chair confinement Marked restriction SLR bilaterally Persistent back pain and stiffness	3 Exploration laminectomy wound Excision of considerable scar about dural sac and nerve roots	3 Patient again ambulatory without crutches and back in college Able to swim Marked improvement in back and leg pain back motions and SLR Difficult to evaluate neurologically because of the considerable spastic paralysis of lower extremities
36		52	Re injury to back in rear end auto collision 12 months after surgery Developed pain left low back and left thigh numbness left foot and some left calf atrophy No improvement after exercise program	Excision of reherniated lumbar 4 disc left and some scar about the root	Last seen 78 months after original surgery Asymptomatic Neurologically negative
37	1	18	1 1 month after surgery had a fall Restriction SLR and flexion lumbar 5 neurologic finding right Discogram 17 months later showed herniation lumbar 4 disc	1 Excision of a central protrusion lumbar 4 disc	1 Improved
	2	31	2 3 months after initial surgery had second injury Limitation SLR and back motion Stocking hypesthesia right leg Numerous other injuries	2 Excision of reherniated lumbar 4 disc right Lumbar and sacral 1 roots bound down by scar	2 Failure Left leg pain SLR 75 right 70 left with back pain Stocking hypesthesia right leg Porphyrinuria diagnosed Conversion hysteria Attempted suicide Under psychiatric care

TABLE 1—D (cont.)

Case	Months after reoperation	Indication for reoperation	Operation and surgical findings	Result and remark
40	5	Developed constant back and right leg pain Catching pain in back on arising SLR and flexion free No neurologic findings Discography of lumbar 3 advised and performed	Excision of herniated lumbar 3 disc	Good result Symptoms relieved after this procedure Has had numerous injuries since including rear end auto collisions Sustained compression fractures thoracic 9 and lumbar 1 65 months after initial surgery Has had some recurrence right low back and right calf pain but no positive neurologic findings Touches floor
41	1 9	1 Persistent severe right sciatica Local tenderness Neurologically negative Extremely nervous	1 Bilateral *Adkins* fusion attempted with iliac bone lumbar 4-5 and lumbar 5-sacral 1	1 Persistent right leg pain No definite neurologic findings
	2 18	2 Persistent right sciatica Traction on right lumbar 5 root at surgery (under local anesthesia) reproduced pain	2 Exploration revealed intra and extraneural scar right lumbar 5 root Section of sensory branch right lumbar 5 root attempted	2 Improved for several months but then had recurrence right leg pain Developed intermittent locking ... right leg

3	39	3 N n union 1 *lkins* fusion at lumbar 4 5 level Complained of severe right sciatica Slight lumbar 5 motor deficit Slight sacral 1 sens ry deficit	3 Exp l ratic n *Adkins* fusion soli l at lumbar 5 acral 1 level Lateral *Hill s* fusi n lumbar 4 to acral 1 attempted	3 Unimj rove l l ersistent right leg pain
4	53	4 Severe radicular pain down right sacral 1 distributi n	4 Re exploration right lumbar 5 acral 1 roots Sacral 1 r ot clear Lumbar 5 root carred considerably Fusic n solid lumbar 5 sacral 1 but not at lumbar 4 5	4 Symptoms unimproved Inconstant stocking hypesthesia entire right leg and left leg below knee
44	1)	l ersistent right sciatica and left low back pain Able to touch flo r Neur l gical examinati n negative	Exploration Ring of scar ab out right lumbar 5 r ct cuff excised	Failure Continues to have const int back pain Mild sacral 1 findings bilaterally l ersistent pain prcbably due to intraneural scar formation
49	71	Asymptomatic for 5 years after initial decompression elsewhere and then developed low back ache and catching j ain No recurrence of leg pain	Exploration Large meningocele found di sected free and closed Some ectopic b one f rmation pre ent Disc material exci ed at lumbar 3 an l 4 Developed wound infection j ostoperatively	C omplete relief of symptoms Examination negative

TABLE

Synopsis of

Case	Occupation	Length of disability (months)	Ability to resume former occupation	Length of follow up (months)	Further forward displacement and per cent of increase
4	Physician	1	Complete	144	Early first to mid first degree 9 per cent
5	Housewife	7	Complete	123	Early first to late first degree 27 per cent
6	Salesman	1	Complete	37	Early first to mid first degree 6 per cent
7	Housewife and secretary	1 5	Complete	118	None
8	Laundryman	1	Complete	34	None
10	Housewife	2	Complete	33	10 per cent progression of *mid first degree*
11	Secretary	10	Complete	32	None
12	Housewife	1	Complete	31	None
13	Floor covering contractor	6	Complete	112	5 per cent progression of early first degree
14	Clerk and laborer	1 5	Complete	108	3 per cent progression of early first degree
15	Housewife	2	Complete	109	9 per cent progression of early second degree
16	Clerk and housewife	1 5	Complete	118	Early first to late first degree 33 per cent
19	Medical student	1	Complete	20	None
20	Teamster	2	Complete	16	None
21	Carpenter	45	Complete	37	None
22	Marine electrician	9	Complete	97	None
23	Clerk	2	Complete	9	None
24	Janitor	4	Complete	9[illegible]	None
26	Bookkeeper	5	Complete	5	None

1—E
Results

R ult	R marks
Fair	Able to spend long periods in surgery daily
Fair	Thrown from car ninth day after last surgery Wound torn open Sutured. Healed per *primam* Nervous since Moderate improvement only
Good	Lost from further follow up
Asymptomatic	
Asymptomatic	Lost from further follow up
Good	Lost from further follow up
Good	Lost from further follow up
Asymptomatic	Lost from further follow up
Asymptomatic	Performs all duties connected with installation of floor covering
Asymptomatic	
Good	
Asymptomatic	3 pregnancies postoperatively
As mptomatic	Lost from further follow up
Asymptomatic	Lost from further f llow up
Failure	Now emplo ed as swimming pool maintenance man Work is equally *arduous according to the patient*
Asymptomatic	
Fair	Lost from complete follow up
Good	
Fair	Lost fr m complete follow up

TABLE

Case	Occupation	Length of disability (months)	Ability to resume former occupation	Length of follow up (months)	Further forward displacement and per cent of increase
28	Bookkeeper and housewife	7	Complete	85	None
29	Shipping clerk and housewife	4	Complete	70	Early first to mid first degree 24 per cent
31	Student		Complete	87	None
32	Janitor	2	Complete	74	None
33	Painter	7 5	Complete	9	None
34	Grocery clerk	3	Complete	7	3 per cent progression of mid first degree
35	Teacher	3	Complete	79	6 per cent progression of mid first degree
36	Truck driver	4	Complete	78	5 per cent progression of mid first degree
37	Waitress and housewife	See remarks	See remarks	81	Early first to mid first degree 3 per cent
38	Waitress	9	Complete	77	None
39	Banker	4	Complete	75	None
40	Housewife and magazine sales	8	Complete	75	Early first to mid first degree 8 per cent
41	Housewife and maid	20	Partial	60	None
42	Construction worker	5	Complete	72	None

1 E (cont)

R ult	R ma k
Asymptomatic	Does own housework and laundry Holds full time job and drives 100 miles daily
Good	Developed keloid after surgery Symptoms persisted for some time but cleared after x ray therapy Able to perform work requiring lifting and wrapping of heavy packages
Failure	Classified as failure now because of operative procedures 1 and 2 on Table 1—D Markedly improved after last surgery however
Asymptomatic	73 months after surgery had recurrence of symptoms Prescribed exercise program resumed Again became asymptomatic
Failure	Felt to have a conversion hysteria Industrial litigation Obvious psychosexual abnormality Under psychiatric care Lost from complete follow up
Fair	Lost from complete follow up
Asymptomatic	Does heavy labor during summer months
Asymptomatic	
Failure	Felt to have a conversion hysteria Disability difficult to evaluate because of psychiatric problems
Asymptomatic	Under treatment before and after surgery for numerous non related medical problems which were cause of prolonged disability
Asymptomatic	
Good	Good result after second decompression Many postoperative injuries caused recurrence of symptoms but patient now has minimal complaints and is again considered a good result
Failure	Ability to resume occupation was complete 4 months after initial surgery but only partial after other procedures
Fair	Returned to lighter work 5 months after surgery but later resumed regular job 17 months after surgery had onset of new symptoms Disc excision advised but patient has not wished surgery Does extremely heavy work 15 hrs per day

TABLE

Case	Occupation	Length of disability (months)	Ability to resume former occupation	Length of follow up (months)	Further forward displacement and per cent of increase
43	Assembly worker	4	Complete	57	None
44	Housewife	8	Complete	68	9 per cent progression of early first degree
45	Housewife	3	Complete	56	None
46	Brushmaker and housewife	4	Complete	40	None
47	Automobile painter	5	Complete	34	Early first to mid first degree 9 per cent
48	Housewife Very athletic	2	Complete	32	None
49	Welder	8	Complete	96	7 per cent progression of mid first degree
50	Student	3	Complete	24	Mid first to late first degree 22 per cent
51	Student	2	Complete	23	Nominal fourth to true fourth degree after surgery
52	Farmer	See remarks	See remarks	4	None

Asterisk indicates those patients who had operative procedures following the initial decompression Disability indicated is accrued total resulting from all operative procedures

Definition of terminology describing degree of displacement

Spondylolysis = No measurable degree of displacement

First degree = Slipping from 1 to 50 per cent
Early = 1 to 17 per cent
Mid = 18 to 35 per cent
Late = 36 to 50 per cent

1 E (cont)

R sult	Rem rks
Good	Herniated disc probable sole cause of symptoms 2 years after surgery developed right lower quadrant pain History of intermittent claudica tion Aorta calcified Myelo ram and discogram not remarkable 27 months after surgery
Failure	Persistent pain in low back and right calf Unimproved following second operation
Good	Asymptomatic and dismissed from care 3 months after surgery Fell 31 months after surgery and had recurrence of mild back and left leg pain Now classified as good because of the occasional right buttock pain which appeared subsequent to this injury
Good	Rear end auto collision 13 months after surgery Developed mild back ache after this injury
Fair	Good result until auto accident 15 months after surgery Now con sidered fair
Asymptomatic	2 months after surgery had acute recurrence after swimming with flippers S mptoms subsided completel after rest and caudal injections Continues to be very athletic now
Asymptomatic	
Asymptomati	
Good	Has o casional mild backache after working under his car for pro longed periods of time
Good	Patient had not returned to work when last seen No financial need to do so Lost from complete follow up

Second degree = Slipping from 51 to 99 per cent
Early = 51 to 68 per cent
Mid = 69 to 86 per cent
Late = 87 to 99 per cent

Third degree = Slipping of 100 per cent

Fourth degree = Slipping of 100 per cent plus resting of the inferior aspect of the body of the involved vertebra against the anterior aspect of the vertebra below

TABLE

Synopsis of Patients with Previous Fusion Treated

Case	Sex	Age	Occupation	Duration of symptoms (years)	Level and degree of displacement
1	F	21	Waitress and housewife	6	Lumbar 5 first
2	F	42	Bookbinder and housewife	11	Lumbar 5 first
3	F	21	Secretary and housewife	10 worse past 3 years	Lumbar 5 first
9	F	37	Housewife	23	Lumbar 5 first
17	F	34	Housewife	7	Lumbar 5 first
18	F	24	Secretary and housewife	12	Lumbar 5 first
25	F	26	Housewife	Many years	Lumbar 5 first
27	F	37	Mail house order clerk and housewife	Severa year	bar 5 first
30	F	32	Maid and housewife	4	ar

?—A

by Excision of the Loose Arch and Decompression

Previous surgery	Degree of disability before decompression
Excision of loose arch alone and fusion with iliac bone by Dr Gill in 1949	Total
Excision of loose arch and decompression lumbar 5 nerve roots bilaterally followed by fusion with iliac bone lumbar 4 to sacrum by Dr Gill in 1950 Patient had had no back surgery prior to this	Total
Hibbs fusion with iliac bone lumbar 4 to sacrum by Dr Gill Thrombophlebitis was postoperative complication	Moderate
First fusion 1950 failed Coccygectomy 1950 Second fusion 1951 failed All done elsewhere	Total
First fusion 1949 failed Second fusion 1951 failed Both done elsewhere	Total
Exploration and fusion lumbar 4 to sacrum 1950 failed Second fusion 1951 failed Third fusion 1952 failed All done elsewhere	Total
First fusion 1951 failed Second fusion 195? Done elsewhere Did fairly well for 7 or 8 months after second fusion but had recurrence of symptoms after moving furniture	Total
3 attempted fusions lumbar 3 to sacrum done elsewhere 1939 1940 1942 Last fusion reportedly successful	Total
Fusion of lamina of lumbar 4 to spinous process and lamina of lumbar 5 195? No apparent attempt at fusion between lumbar 3 and 4 Done elsewhere	Total

TABLE
Comparison of Symptoms and Findings

Preoperative				
Case	Back pain	Area of radicular pain	Abnormal physical findings	Nerve roots involved
1	Constant severe	Both calves severe on right	Flexion to 6 in of floor Extension limited and painful	Lumbar 5 sacral 1 bilateral moderate
2	Constant severe	Right lower extremity severe	Flexion to 6 in of floor with pain in right low back SLR to 65 on right and 30 on left *Tenderness to palpation lumbo sacral junction*	Lumbar 5 sacral 1 left moderate
3	Moderate	Left leg moderate	Some restriction SLR Tender over loose arch Pain on extension	None
9	Constant moderate	Coccyx moderate left sciatica severe	Flexion to 5 in of floor SLR 90 right 70 left	Lumbar 5 left moderate
17	Constant severe	Both thighs and calves moderate	Flexion to 5 in of floor with reproduction of right sciatica Extension limited and painful	Lumbar 5 bilateral marked on right
18	Constant severe	Right buttock and sciatica severe	Flexion to knees Extension restricted and extremely painful causing right sciatica SLR 70 bilaterally	Lumbar 5 bilateral marked on right Sacral 1 right moderate
25	Constant severe	Left leg	Tender over graft donor site Flexion to 8 in of floor Extension restricted Stocking hypesthesia entire left leg	Lumbar 5 left moderate

ª—B
before and after Decompression Operati n

Postoperat ve m ≈ recent exam na n			
Back pain	Area of radicula pa n	Abn rmal physical fi l ngs a d rem k	N rv roots in f
M ld, only after heavy work. Morning stiff ness relieved by exercise	Right calf occasi nal, mild	Sli ht tightness f SLR n ri ht	Sacral 1 ri ht mild
Aching mild	Coccyx and ri ht leg mild	Limitation of flexion to le el o knees Neur l gi al examina i n negative Fu ion olid	N ne
Aching after heavy work	Occasional left calf pain	SLR free S me back tenderne and discomfort n exten i n Flexes to t u h floor X ray e iden e of degenerati n and p terior al ifi ati n at lumbar 4 disc Fu ion solid at lumbar 4 P eudarthro i at lumbar 5	N ne
Tired feeling after prolonged itting	N ne	Touches fl r Examination negative	N ne
Feeling of weakness	Ri ht calf mild	Exten i n li htly painful. Tou hes metacarpal head to fl r	N ne
Mild, occa ional	Ri ht iati a mild, occasional	Tou hes floor SLR free Back and leg discomf rt now are a sociated mainl with men trual period Some ti htness in back at end f day Re-operated. See Table 2—D	Sacral 1 ri ht mild
Tender over perative area	Ri ht leg	D ing well until 2 weeks prior to last examination when she fell on buttocks. See Table 2—E	Lumbar 5 bilateral, mild

Preoperative				
Case	Back pain	Area of radicular pain	Abnormal physical findings	Nerve roots involved
27	Severe	Aching left leg Severe pain right leg	Marked restriction and pain on SLR Flexion to 10 in of floor Had large adherent stellate scar over sacrum from pressure of cast worn after the fusion	Lumbar 4 right Lumbar 5 sacral 1 bilateral
30	Constant	Coccyx and both legs severe	Walked in flexed position with upper lumbar area hyperextended Generalized hypesthesia right leg	Lumbar 5 bilateral mild

ɪʙ 2—B (cont)

		Po toperat e (most recent e amin t o)	
Back p n	Area of ra licular pain	Abno mal pl y ic l findin s and r mark	N r o t in ol d
Dull ache on left	Aching in left leg	Flexion to 2 in of floor SLR 90 bilaterally Plastic correction of scar strongly advised See Table ?—D	Sacral 1 left mild
Catching occasionally	None	Reoperated See comments on Table 2—D Was asymptomatic and negative 4 days prior to in jury described on Table 2—D Recently developed catching in back. Flexion free but slight two stage recovery	Sacral 1 left mild

TABLE
Correlation of Surgical Findings with

Case	Preoperative n ur lo ical fin lin s: Nerve roots in olv l	Surgi a: Lev l of pseu larthrosi	Amount of motion at 1 fect in pars int rarticulari f invol l v rtebra
1	Lumbar 5 sacral 1 bilateral moderate	Lumbar 4 and 5 Lumbar 5 and sacral 1	Perceptible only afte removal 0 25 in o bone
2	Lumbar 5 sacral 1 left moderate	None	Marked
3	None	Fusion solid	None
9	Lumbar 5 left moderate	Lumbar 4 and 5 Lumbar 5 and sacral 1	Barely perceptible
17	Lumbar 5 bilateral marked on right	Lumbar 4 and 5 Lumbar 5 and sacral 1	Barely perceptible
18	Lumbar 5 bilateral marked on right Sacral 1 right moderate	Lumbar 4 and 5 Lumbar 5 and sacral 1	Barely perceptible only after removal 0 25 in of bone
25	Lumbar 5 left moderate	Frank nonunion at lumbar 4-5 and lumbar 5-sacral 1 with overgrowth of bone above lamina of lumbar 4 which buttressed against spinous process of lumbar 3 Numerous fragments of bone over surface of fusion mass	Barely perceptible
27	Lumbar 4 right Lumbar 5 and sacral 1 bilateral	Nonunion at lumbar 3 Questionable nonunion at lumbar 5 Little motion present however	Barely perceptible
30	Lumbar 5 bilateral mild	Lumbar 4-5	Barely perceptible

L 2—C
Preoperative Neurological Findings

fin lin rs	
F b ca t t n ious a	Disc p tholo y ard fur l mtr n
Bilateral larger on right	Fusion mass extended over lamina of lumbar 4 and pressed dura
Bilateral compressing both lumbar 5 roots	No disc pathology
Present on left	None noted
Bilateral larger on left	None noted
Bilateral larger on right with adhesions to lumbar 5 root right	Dura compressed by sinking in of fusion mass
Bilateral larger on right	Dura compressed b mass of ligamentum flavum b lamina of lumbar 3
Bilateral larger on left with compression left lumbar 5 root Right lumbar 5 root clear	Adhesions under graft to dura Considerable ligamer flavum present Lumbar 5 disc markedly collapsed Imp ble to remove di c material Lumbar 4 disc normal
Bilateral and compressing both lumbar 5 roots	Lumbar 3 disc degenerated bегg and bulging Lumbar 4 5 discs normal
Bilateral	Lumbar 4 dis pr minent on right Lumbar 5 di c colla

TABLE
Synopsis of

Case	Occupation	Length of disability (months)	Ability to resume former occupation	Months of follow up after decompression	Further forward displacement and per cent of increase**
1	Waitress and housewife	4	Complete	24	None
2	Bookbinder and housewife	28	Complete	114	Early first to late first degree 25 per cent
3	Secretary and housewife	3	Complete	146	None
9	Housewife	7	Complete	32	None
17	Housewife	2	Complete	28	None
18	Secretary and housewife	8 5	Complete	113	Early first to mid first degree 15 per cent
25	Housewife	3	Complete	9	Early first to mid first degree 19 per cent
27	Mail house order clerk and housewife	7	Complete	95	4 per cent progression of early first degree
30	Maid and housewife	18	Complete	86	None

Asterisk indicates those patients who had operative procedures following the initial decompression Disability indicated is accrued total resulting from all operative procedures

Definition of terminology describing degree of displacement

Spondylolysis — No measurable degree of displacement

First degree — Slipping from 1 to 50 per cent
Early — 1 to 17 per cent
Mid — 18 to 35 per cent
Late — 36 to 50 per cent

—C

Preop rative Neurological Findings

Findin s	
F broca t la n us ma	Di patholo y a d dural ompr s n
Bilateral larger on right	Fusion mass extended over lamina of lumbar 4 and com pressed dura
Bilateral compressing both lumbar 5 roots	No disc pathology
Present on left	None noted
Bilateral larger on left	None noted
Bilateral larger on right with adhesions to lumbar 5 root right	Dura compressed by sinking in of fusion mass
Bilateral larger on right	Dura compressed by mass of ligamentum flavum below lamina of lumbar 3
Bilateral, larger on left with compression left lumbar 5 root Right lumbar 5 root clear	Adhesions under graft to dura Considerable ligamentum flavum present Lumbar 5 disc markedly collapsed Impossi ble to remove disc material Lumbar 4 disc normal
Bilateral and compressing b th lumbar 5 roots	Lumbar 3 disc degenerated boggy and bulging Lumbar 4 and 5 discs normal
Bilateral	Lumbar 4 disc prominent on right Lumbar 5 disc collapsed

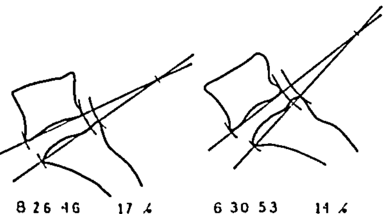
TABLE 2—D
Reoperations

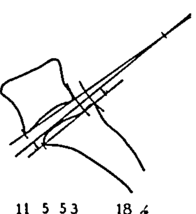
Case	Months after [illegible]		Indication for reoperation	Operation and surgical findings	Result and remarks
2	1	5	1 3 months after surgery developed severe pain over operative area with radiation to right buttocks and coccyx X rays showed shifting of grafts toward midline over dura	1 Exploration Excision of thick scar between dura and graft Excision of bone chips compressing terminal end of spinal theca	1 Relief of coccygeal and right leg pain for about six weeks
	2	14	2 Recurrence of coccygeal and right leg pain	2 Exploration Excision of thick scar over dura Excision of adhesions between right sacral 1 root and wall of canal also between pedicle of lumbar 5 and right fifth lumbar nerve root Refusion with rib grafts lumbar 4 to sacrum	2 Fusion solid Right leg pain disappeared Neurological examination continued to be normal
	3	39	3 Recurrence of coccygeal pain	3 Exploration Fusion solid Excision thin scar about dura and right sacral 1 root Small dural arachnoid cyst found	3 Patient had spinal fluid fistula for 4 to 5 weeks after surgery Temporary relief of symptoms only although neurological examinations have remained negative
18	1	8	1 Aching in back and local soreness Some pain right buttocks No leg pain X ray evidence of new bone formation about previous fusion site	1 Exploration Excision of osseous proliferation in scar overlying dural sac	1 Much improved Free back motion No radicular pain 1 month after surgery was struck in back by doorknob *Developed soreness* over sacrum and later radicular pain int right buttock and leg

		13	2 Per l tent l acl a l with a lia tion to coccyx Sacral 1 findings left Slight pa m on back moti n	? l pl rati n l x f i n of al out lura an l r ght luml a 5 a d sacral 1 ro ts Exci ion of degenerated disc material at lumbar 4	- In p ve l Continu l t have son c back and right leg pain Became pregnant 7 months later Had some increase in back pain but pregnancy and delivery much easier than with other child Did very well afterward Essentially lost back pain and had only mild right leg discomfort
	3	68	3 4 months previously slipped and twisted back Had recurrence of back and right leg pain Mil l lumbar 5 and sacral 1 findings right Discogram howed protru sion at lumbar right	3 Exploration Freeing of right lumbar 5 root which was bound to annulus of lumbar 5 disc by car Excisi n of disc material at lumbar 5	3 Improved but continued to have some back and right leg discom fort Injured 3 years later while water skiing Had some increase in symptoms Mild lumbar 5 findings present on right
	4	110	4 3 months before surgery had belly flop while water kiing Developed more right leg pain Later deve loped 5 in atrophy right calf and ome right lumbar neurologi changes	4 Rehermation lumbar 4 disc right	4 Last seen 3 5 months after sur gery Calves equal No sensory changes Right heel jerk dimin ished Much improved Con ider ed as fair result
27		31	Unhealed ulcer and large adherent stellate scar ver sacrum cau ed by pres ure of ca t worn after fu sion	Biop y of scar No malignancy No infection Scar exci ed Tran p i tion of gluteal skin flap performed D ne el ewhere at our recommenda tion	Excellent
30	1	15	1 7 months after decompression fell on buttocks Devel ped in ability to straighten bacl and paresthe ias in feet Bizarre pos ture SLR free Flexi n to 2 in of fl or Neurologically negative	1 Exploration Done el ewhere Adhe ions reporte l	1 Developed wound infection Seen by us ? years later Had stock ing hype thesia left leg No re flex or motor abn rmality No atrophy SLR free Dia tasis of pinalis mu cles Considerable back stiffnes

TABLE 3

Case 5 Female Birth Date 6 15 [illegible]   Date of Surgery 11 5 51





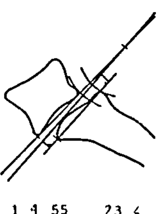


TABLE 4
Postoperative Progression of Displacement According to Age

Age at surgery (years)	Number of Patients		Average postoperative progression of displacement	
	(Males)	(Females)	(Males)	(Females)
25 or under	1	4	3 %	19 %
26 to 30	0	2	0 %	23 %
31 to 35	1	0	5 %	0 %
36 to 40	4	3	5 %	5 %
41 to 45	1	2	9 %	17 5 %
46 to 50	1	1	7 %	24 %
51 to 55	0	1	0 %	9 %
56 to 60	1	0	9 %	0 %

TABLE 5
Postoperative Progression of Displacement According to Sex

	Number of patients	
	Males	Females
Sex of patients	21 (40 4 %)	31 (59 6 %)
Patients with postoperative progression of displacement	9 (42 8 %)	13 (41 9 %)
Average displacement in patients with post operative progression of displacement	9 (59 %)	13 (16 0 %)
Average follow up in all patients	21 (62 months)	31 (65 months)
Average follow up in patients without post operative progression of displacement	12 (51 months)	18 (56 months)
Average follow up in patients with post operative progression of displacement	9 (77 months)	13 (79 months)

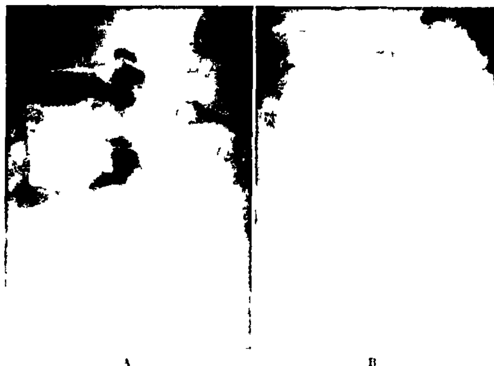


Fig 1 Case 2

A Roentgenogram four months before a combined decompression and fusion in a forty two year old female

B Roentgenogram 114 months after surgery shows a 25 per cent progression of the first degree spondylolisthesis



A B

Fig 2 Case 3

A Roentgenogram ten months prior to the decompression operation in a twenty one year old female Re exploration because of persistent symptoms showed solid fusion from lumbar 4 to the sacrum and a decompression was done on the left (The roentgenogram has been retouched)

B Roentgenogram 146 months after the decompression pro edure There has been no progression of displacement despite the pseudarthrosis at the 5th lumbar interspace

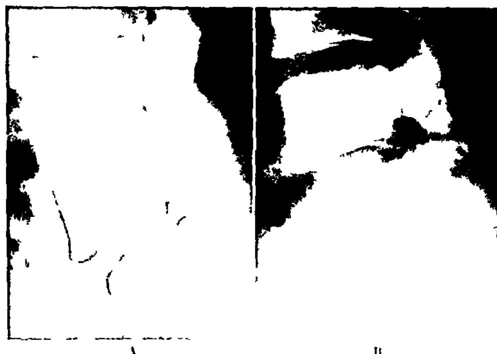


Fig 3 Case 4

A Roentgenogram eleven months before the decompression operation in a forty one year old male (The roentgenogram has been retouched)

B Roentgenogram 144 months after surgery shows a 9 per cent progression of the first degree spondylolisthesis (The roentgenogram has been retouched)

Fig 5 Case 7 →

A Roentgenogram immediately prior to the decompression operation in a twenty three year old female (The roentgenogram has been retouched)

B Roentgenogram 118 months after surgery shows no progression of displacem-
The roentgenogram has been retouched)

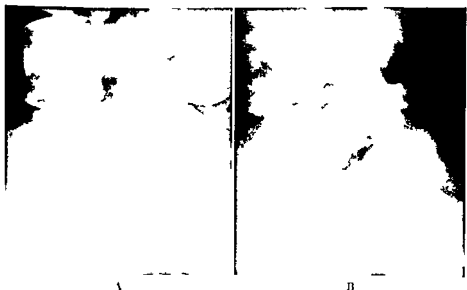
A

B

Fig 4 Case 5

A Roentgenogram sixty two months before the decompression operation in a woman thirty years of age at the time of surgery

B Roentgenogram 123 *months after surgery* shows a 27 *per cent progression* of the first degree spondylolisthesis



A

B

Fig 5 Case 7



Fig 13 Case 33

A Roentgenogram before the decompression operation in a thirty eight year old female (The roentgenogram has been retouched)

B Roentgenogram eighty five months following surgery shows no progression of displacement (The roentgenogram has been retouched)

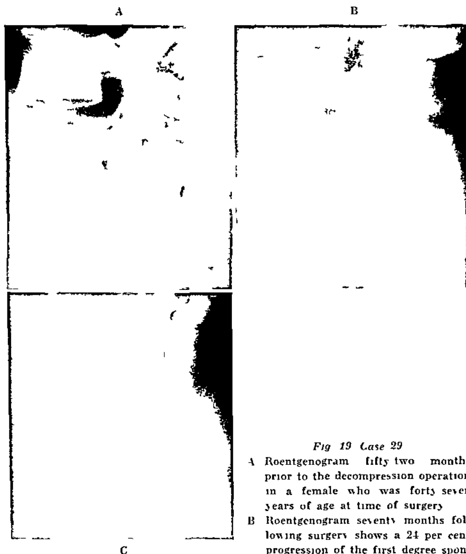


Fig 19 Case 29

A Roentgenogram fifty two months prior to the decompression operation in a female who was forty seven years of age at time of surgery

B Roentgenogram seventy months following surgery shows a 24 per cent progression of the first degree spondylolisthesis (The roentgenogram has been retouched)

C Roentgenogram seventy months following surgery In this film sand bags weighing twenty four pound were placed on the patient s shoulders but no essential change in the position of the body of the fifth lumbar vertebra is noted with this added weight (The roentgenogram has been retouched)

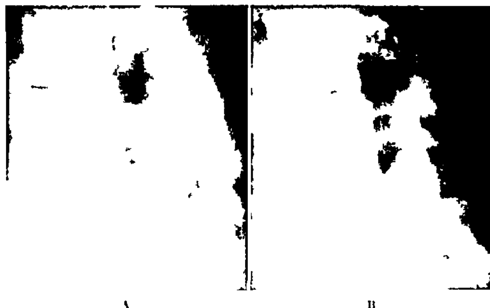


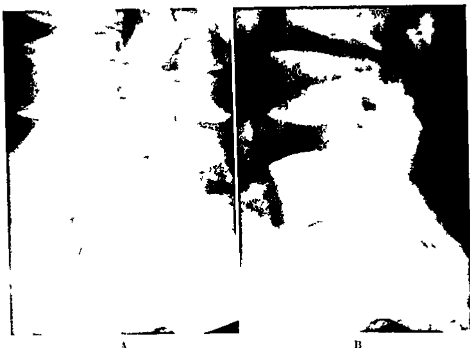
Fig 0 Case 30

A Roentgen gram thirteen months before the decompression operation in a female who was thirty two years of age at the time of surgery There is a first degree spondyl listhesis of the fourth lumbar vertebra Two years previously a fusion from the fourth lumbar vertebra to the sacrum was attempted elsewhere and resulted in pseudarthrosis

B Roentgen gram eighty six months following the decompression shows no progression of displacement



Fig 21 Case 21



A B

Fig 22 Case 32

A Roentgenogram four months prior to the decompression operation in a fifty one year old male (The roentgenogram has been retouched)

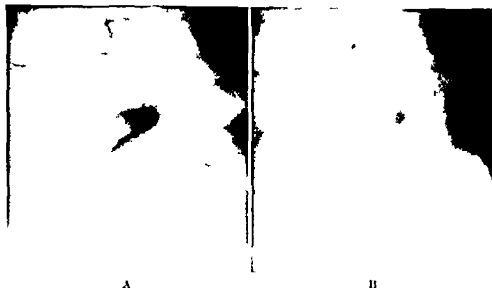
B Roentgenogram seventy four months following surgery shows no progression of displacement (The roentgenogram has been retouched)

←

Fig 21 Case 31

A Roentgenogram twenty one months prior to the decompression operation in a woman who was twenty one ears of age at the time of surgery (The roentgenogram has been retouched)

B Roentgenogram eighty three months following the decompression procedure Interbody fusion at the fourth and fifth lumbar levels was attempted elsewhere forty eight months following the initial surgery and resulted in pseudarthrosis No progression of displacement has occurred (The roentgenogram has been retouched)



A B

Fig 3 Case 35

A Roentgen gram immediately pri r t the dec mpre si n operati n in a thirty seven year old male (The roentgen gram has been ret uched)

B R entgenogram seven m nth f ll wing urgery h ws a 3 per cent progressi n f the first degree sp n lyl li the is (The roentgen gram has been retouched)

A B

Fig 35 Case 35

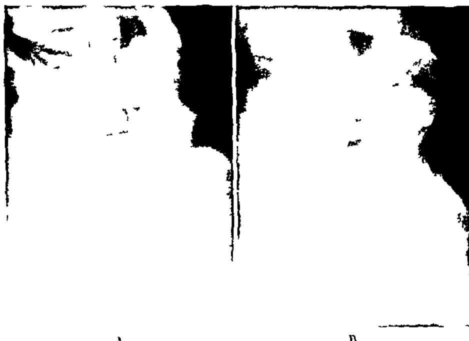


Fig 25 Case 36

A Roentgenogram immediatel prior to the decompression operation in a thirty eight year old male (The roentgenogram has been retouched)

B Roentgenogram seventy eight months following surgery shows a 5 per cent progression of the first degree spondylolisthesis

←

Fig 24 Case 35

A Roentgenogram three months following the decompression operation in a thirty six year old male Preoperative roentgenograms were not available (The roentgenogram has been retouched)

B Roentgenogram seventy nine months following surgery shows a 6 per cent progression of the first degree spondylolisthesis



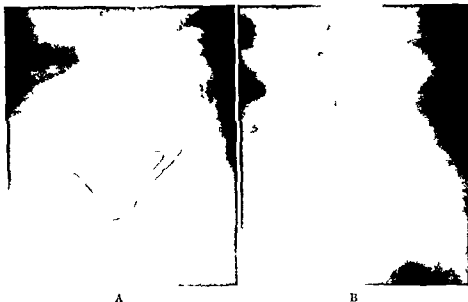
Fig. 23 Case 33

A. Roentgenogram immediately prior to the decompression operation in a thirty-seven year old male (The roentgenogram has been retouched)

B. Roentgenogram seven months following surgery shows a 3 per cent progression of the first degree spondylolisthesis (The roentgenogram has been retouched)

A

B



A B

Fig 78 Case 39

A Roentgenogram two months following the decompression operation in a forty five year old male Preoperative roentgenograms were not available (The roentgenogram has been retouched)

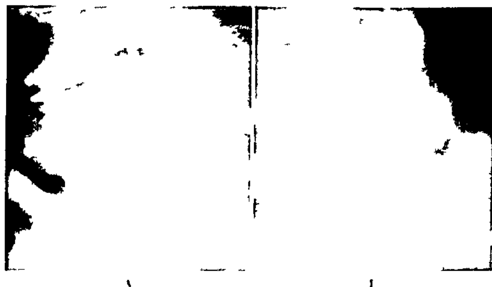
B Roentgenogram seventy five months following surgery There has been no progression of displacement (The roentgenogram has been retouched)

A B

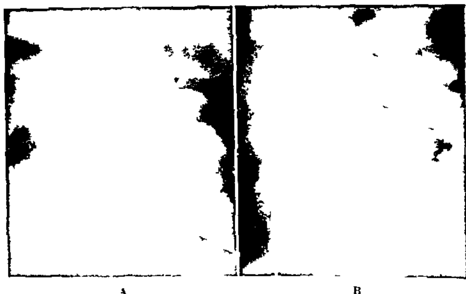
Fig 9 Case 10

A Roentgenogram immediately prior to the decompression operation in a thirty six year old female (The roentgenogram has been retouched)

B Roentgenogram seventy five months following surgery shows an 8 per cent progression of the first degree spondylolisthesis (The roentgenogram has been retouched)



A B



A B

Fig 31 Case 5

A R entgenogram immediately prior to the decompression operati n in a forty seven year old male

B Roentgenogram seventy two months following surgery shows no progression of displacement

←

Fig 30 Case 41

A Roentgenogram two months before the decompression operation in a thirty year old female (The roentgenogram has been retouched)

B Roentgenogram sixty months after surgery shows no progression of displacement



Fig 2 Case 43

A Roentgen gram one month prior to the decompression operation in a fifty seven year old female (The roentgen gram has been retouched)

B Roentgen gram fifty seven months following surgery shows no progression of displacement (The roentgen gram has been retouched)



Fig 3 Case 44

A Roentgen gram fifty three months prior to the decompression operation in a woman who was fifty five years of age at the time of surgery (The roentgen gram has been retouched)

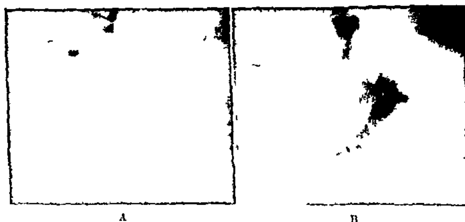
B Roentgen gram [illegible] months after surgery shows a 9 per cent progression [illegible]

A B

Fig 34 Case 45

A Roentgenogram shortly before the decompression operation in a fifty seven year old female (The roentgenogram has been retouched)

B Roentgenogram fifty six months after surgery shows no progression of displacement

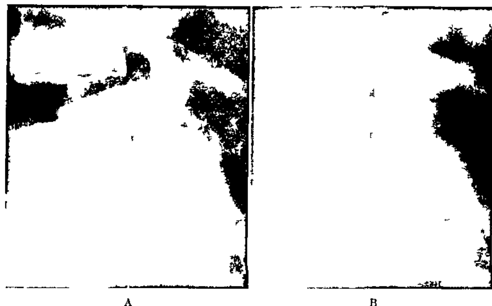


A B

Fig 35 Case 46

A Roentgenogram two months before the decompression operation in a twenty n[illegible] year old female (The roentgenogram has been retouched)

B Roentgenogram forty months following surgery shows no [illegible] n of d placement

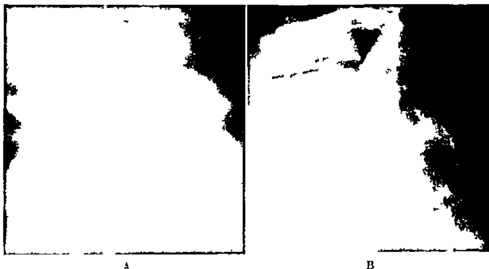


A B

Fig 36 Case 47

A Roentgenogram two years prior to the decompression operation in a male who was fifty seven years of age at the time of surgery

B Roentgenogram thirty four months after surgery shows a 9 per cent progression of displacement



A B

Fig 37 Case 48

A Roentgenogram nine months prior to the decompression operation in a forty six year old female

B Roentgenogram thirty two months after surgery shows no progression of displacement

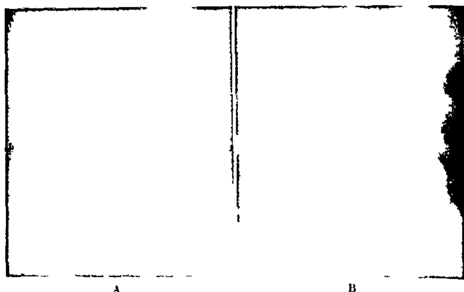


Fig 38 Case 49

A Roentgenogram immediately prior to the decompression operation in a forty eight year old male There is a first degree spondylolisthesis of the fourth lumbar vertebra (The roentgenogram has been retouched)

B Roentgenogram ninety six months following surgery shows a 7 per cent progression of displacement (The roentgenogram has been retouched)



Fig 39 Case 50

A Roentgenogram thirteen months before the decompression operation in a girl who was fourteen years of age at the time of surgery (The roentgenogram has been retouched)

B Roentgenogram two months before surgery shows no progression of displacement

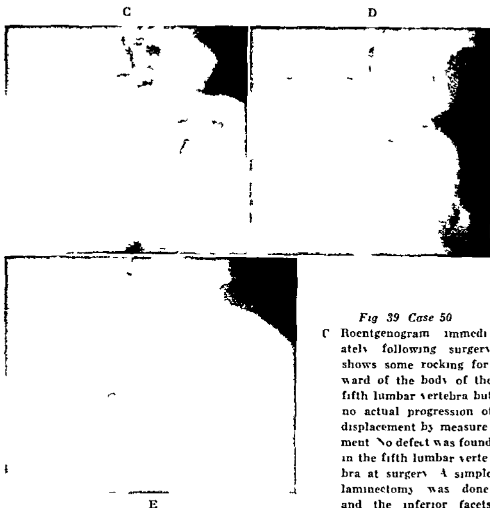


Fig 39 Case 50

C Roentgenogram immediately following surgery shows some rocking forward of the body of the fifth lumbar vertebra but no actual progression of displacement by measurement No defect was found in the fifth lumbar vertebra at surgery A simple laminectomy was done and the inferior facets were left intact

D Roentgenogram nine months following surgery still shows no progression of displacement

E Roentgenogram twenty four months after surgery shows a 22 per cent progression of displacement

---

Fig 40 Case 51 →

C Roentgenogram two months prior to the decompression operation now shows a *fourth degree spondylolisthesis of the fifth lumbar vertebra* (*The roentgenogram has been retouched*)

D Roentgenogram one month following the decompression operation At surgery solid healing of the defect in the pars interarticularis on the left and spontaneous fusion of the inferior facets of the fifth lumbar vertebra to the superior facets of the sacrum bilaterally were found (The roentgenogram has been retouched)

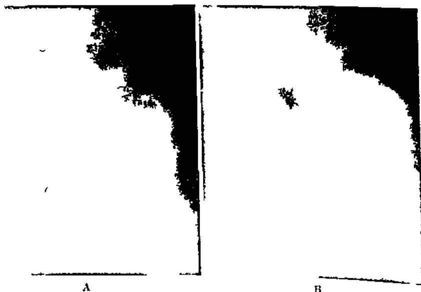


Fig 40 Case 51

A Roentgenogram twenty six months before the decompression operation in a boy who was fourteen years of age at the time of surgery (The roentgenogram has been retouched)

B Roentgenogram sixteen months prior to surgery shows continued progression of displacement (The roentgenogram has been retouched)

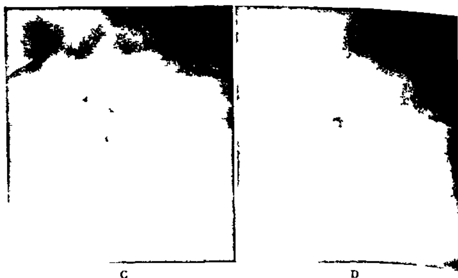


Fig 40 Case 51

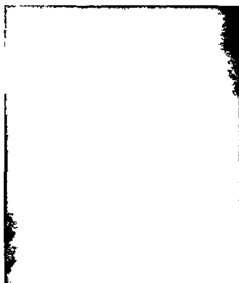




Fig 40 Case 51

E Roentgenogram eighteen months after surgery (The roentgenogram has been retouched)

F Roentgenogram twenty three months after surgery (The roentgenogram has been retouched)



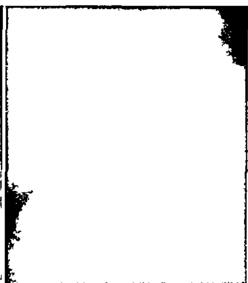


Fig 41 Case 5?

A Roentgenogram immediately prior to the decompression operation in a fifty two year old male There is a first degree spondylolisthesis of the fourth lumbar vertebra

B Roentgenogram four months following surgery shows no progression of displacement

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LEGG-PERTHES DISEASE IN THE DOG

AKADEMISK AVHANDLING

som med tillstånd av
Kungl Veterinarhogskolans Lararkollegium
for erhallande av veterinarmedicinsk doktorsgrad
offentligen forsvaras i Veterinarhogskolans Aula
fredagen den 3 februari 1967 kl 9 15

Av

GUNNELA LJUNGGREN
Veterinär

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO 95

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LEGG-PERTHES DISEASE IN THE DOG

by

GUNNELA LJUNGGREN

MUNKSGAARD
Copenhagen 1967

TO MY PARENTS

Contents

Introduction and Object of Investigation

Aseptic bone necrosis has been described in different parts of the skeleton in the dog The best known example is that of the head of the femur In the first detailed description of the disease (Moltzen Nielsen 1938) the term Calve Perthes disease was used Olsson (1958) adopted the term Legg Perthes disease commonly used in human medicine

Over the last few years dogs with Legg Perthes disease have been studied at the Royal Veterinary College in Stockholm The results of these studies are described in this monograph

On the basis of clinical and morphological observations a hypothesis on the etiology has been postulated and experimentally tested

The results of conservative and surgical treatments have been evaluated from clinical and radiographical follow up studies

The disease in dogs is compared with Legg Perthes disease in man

CHAPTER I

Review of Literature

Legg Perthes disease has been reported only in dogs of small *breeds* Schnelle (1937) described 12 cases of Legg Perthes disease in Fox Terriers In both Moltzen Nielsen s (1938) material of 19 cases and in Olsson s (1958) series of 64 cases only dogs belonging to small breeds were represented

There was no information available in the literature concerning the *incidence* of Legg Perthes disease in the dog

With regard to *age distribution* Schnelle (1937) stated that the disease started between 3 and 10 months of age Moltzen Nielsen (1938) gave an age variation from 5 to 8 months for the initially observed clinical signs Hulth *et al* (1962) reported on 7 cases in which symptoms also started from 5 to 8 months of age

In Moltzen Nielsen s (1938) material the *sex distribution* was 11 males and 8 females Hulth *et al* (1962) described 7 cases which included 5 male dogs

The initial *clinical sign* was lameness which may appear insiduously or fulminantly The affected leg was usually somewhat shortened and exhibited some degree of muscle atrophy Abduction was markedly inhibited (Schnelle 1937 Moltzen Nielsen 1938 Olsson 1958)

The importance of *radiographical examination* for the definite diagnosis of Legg Perthes disease in the dog was emphasized by all authors Schnelle (1937) described the radiographical findings in one case as "flattening of the femoral head almost to the point of disappearance In other cases the flattening was less severe and sometimes involved only the weight bearing surface The acetabulum usually appeared normal Only in advanced cases was there a change in the shape of the acetabular rim

Flattening of the epiphysis with disturbance of bone formation and calcification was described in early cases by Moltzen Nielsen (1938) During the healing period the femoral head widened especially the anterior part

Olsson (1958) also stressed the need for radiographical examination in diagnosing Legg Perthes disease He found in rare cases however that dogs were submitted too early for any radiographical demonstration of lesions The

first visible sign was a focally decreased density in the femoral epiphysis and metaphysis Further loss of density occurred sometimes with fragmentation and flattening of the femoral head Only in advanced cases did the acetabulum show arthrotic changes

In Moltzen Nielsen s (1938) series of 19 cases 1 was bilateral In 7 cases described by Hulth *et al* (1962) 4 occurred on the right side and 3 on the left side

Olsson (1958) held conservative *treatment* as the method of choice Reports on surgical treatment (Spreull 1961 Ormrod 1961 Rex 1963) are too limited for evaluation

The *pathological anatomy* of Legg Perthes disease in the dog has not been the subject of extensive studies Osteonecrosis and reparative processes including fibrosis and new bone formation have been described (Moltzen Nielsen 1938 Hulth *et al* 1962 Paatsama *et al* 1966)

The *etiology* is unknown Schnelle (1937) Moltzen Nielsen (1938) and Olsson (1958) all emphasized that the disease occurs only in small dogs This points strongly toward the importance of the constitution

CHAPTER II

Maturation of the Femoral Head in the Dog Morphogenesis and Hormonal Influences

The literature review showed that the osteonecrosis of the femoral head in Legg Perthes disease occurs in miniature breeds only It also showed that the disease occurs in the young individual

The literature thus indicated that Legg Perthes disease in the dog is a constitutional disease which manifests itself during the growth period

A short introduction to the physiological events involved in skeletal maturation (Weinmann & Sicher 1955) seems appropriate

Longitudinal growth of long bones depends on the activity of the growth plates and to a far lesser degree of the articular cartilage Flat bones grow from sutures and from articular cartilage where present e g mandible scapula Longitudinal growth of vertebrae occurs in the dog as well as in most domesticated animal species from true epiphyseal growth plates and from the cartilaginous end plates

The growth from the epiphyseal growth plate is initiated by mitotic division of resting cartilage cells this process is believed to be controlled by somatotrophin Further differentiation into columnar and vesicular cartilage is believed to be under the influence of thyroxin

Retardation and cessation of longitudinal growth of bones is a function of sex hormone activity The sex hormones counteract the effect of somatotrophin on the division of resting cartilage cells Consequently there is a gradual narrowing of the growth plate as a first response to sex hormones The plate is eventually penetrated and replaced by trabeculae which thus unite the previous metaphysis and epiphysis These processes are referred to as closure of the epiphyseal growth plate

Lateral growth of bones is achieved from periosteum and endosteum This surface apposition of bone by osteoblasts is *stimulated* by sex hormones Transversal growth of bone (as a tissue) and therefore of bones (as organs) is thus accelerated with sexual maturity

The elucidation of two questions appears to be a fundamental basis for a study of Legg Perthes disease in the dog

A Are there morphological differences in the femoral head between miniature dogs and normal sized dogs that will explain the breed predisposition?

B Are there differences in the time of influence of sex hormones in miniature dogs and normal sized dogs?

I Material and Methods

A Morphogenesis of Femoral Head

Femoral heads were collected from dogs up to 12 months of age which were submitted to necropsy for other reasons than skeletal disease The material included 16 miniature dogs and 40 normal sized dogs

Thin mid sagittal slices of the proximal end of femur were demineralized under water pump vacuum in 10 per cent formic acid buffered to pH = 4 5 with sodium citrate After paraffin embedding they were sectioned at 6 microns and stained with hematoxylin and eosin (H&E) and toluidine blue

Determination of the skeletal maturation was made from histological examinations of the epiphyseal growth plate Four developmental stages were recognized viz.

Stage 0 = maximal activity of growth plate
Stage 1 = growth plate markedly narrowed with cell zones poorly differentiated
Stage 2 = partial perforation of growth plate
Stage 3 = complete closure of growth plate

The developmental stages were plotted on the ordinate and the age in months on the abscissa in Fig 1 In the calculation of regression equations cases before and beyond the slope were excluded The total material used in establishing the closure period as a function of age included 6 miniature dogs and 8 normal sized dogs

B Hormonal Influences

Questionaires were sent out to breeders of miniature dogs normal sized dogs and acromegalic dogs Information on breed date of birth and date of first heat period was requested

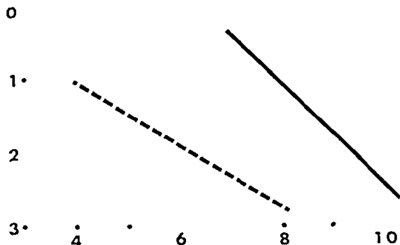


Fig 1 Time of closure of proximal growth plate of femur
Ordinate
Stage 0 = maximal activity of growth plate
Stage 1 = growth plate markedly narrowed with cell zones poorly differentiated
Stage 2 = partial perforation of growth plate
Stage 3 = complete closure of growth plate
Abscissa Age in months
Short black—short white regression line (Y = 0 40 X—0 40) normal dogs of miniature breeds
Long black—short white regression line (Y = 0 42 X—0 67) dogs with Legg-Perthes disease
Solid black regression line (Y = 0 71 X—4 64) normal sized dogs

2 Results

A Morphogenesis of Femoral Head

a Maturation of the epiphyseal growth plate

Closure of the epiphyseal growth plate began at the age of 4 month in miniature dogs and at 7 months in normal sized dogs *Complete closure never ocurred later than at 8 months in miniature dogs and never earlier than at 9 months in normal sized dogs* The regression lines of closure as function of age are presented in Fig 1

Statistical analyses proved

1 Closure of the proximal epiphyseal growth plate of femur occurred at an earlier time in miniature dogs than in normal sized dogs ($P < 0\,001$)

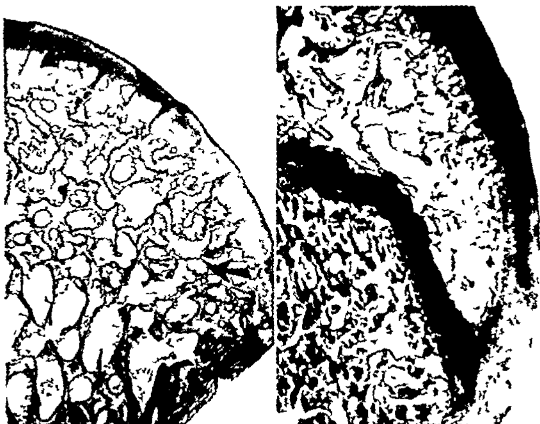


Fig 2 Miniature dog Griffon female 8½ months old Head of femur Thick area of calcified cartilage demarcated from rest of articular cartilage by thin basophilic transversal line (curved arrow) Thick trabeculae Growth plate completely closed level of previous location indicated by straight arrow H&E x 15

Fig 3 Normal sized dog Collie female 8½ months old Head of femur Calcified cartilage poorly defined Trabeculae considerably thinner than in miniature dog in Fig 2 Growth plate persists Note difference in basophilia of cartilage in the two figures H&E x 15

2 Time period involved in closure processes was the same in miniature dogs and in normal sized dogs (slope and scatter of regression lines not different $P > 0.05$)

The histological differences in skeletal maturation in miniature dogs and in normal sized dogs are illustrated in Figs 2 through 4

The femoral heads in Figs 2 and 3 were from a miniature dog and from a normal sized dog respectively both female The chronological ages were identical 8½ months but the skeletal maturation of the miniature dog was considerably further advanced an estimate of at least two months seems reasonable



Fig 4 Normal sized dog Spit female 10½ months old Head of femur Growth plate very poorly differentiated with resting cartilage forming about one half of the width perforation of growth plate (Stage 2) Epiphyseal and metaphyseal trabeculae thickened as response to sexual maturation H&E x 45

b Histology of articular cartilage and trabecular bone

Age changes in articular cartilage and trabeculae coincided with those of the epiphyseal growth plate in miniature dogs and normal sized dogs

The histological differences between miniature dogs and normal sized dogs are illustrated in Figs 5 and 6 Neither in miniature dogs nor in normal sized dogs was there a strict correlation between the chronological age and the skeletal maturation Fig 7 emphasizes this point The section from the femoral head of a male Pug showed an extremely wide zone of calcified cartilage and markedly thickened epiphyseal trabecluae The chronological age of the dog was 5 months but the skeletal maturation was approximately that of a 7 month-old miniature dog or a 10- to 11 month-old normal sized dog

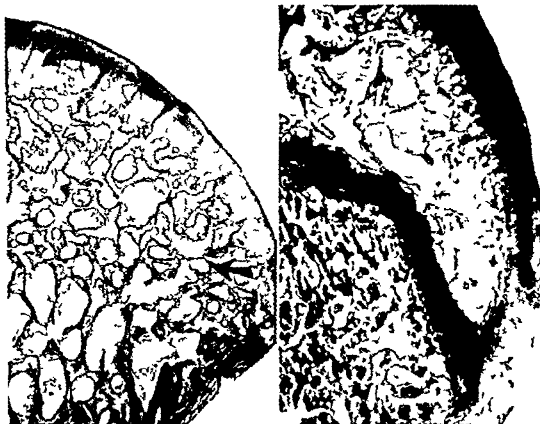


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Fig 7 Miniature dog Pug male 5 months old Head of femur Extremely wide zone of calcified cartilage Thick trabeculae H&E x 45

been weak ("silent heat) or simply not observed because not expected The femoral head shown in Fig 2 was from an 8½ months old Griffon The figure shows complete closure of the growth plate the skeleton therefore must have been influenced by sexual maturation for at least 2 months (see Fig 1) No heat period was ever observed even though the dog was a pet of a veterinarian (the author) who raises Griffons

The information on the first heat period gathered from questionnaires must be evalauted with caution The lowest figures are likely to be accurate but not the higher ones It is evident from the investigation that under any circumstances a relatively greater number of miniature dogs exhibit the first heat period earlier than normal sized dogs Still better evidence of the importance of sexual maturation on body constitution is the significantly later occurrence of the first heat period in acromegalic dogs

500

400

300

200

1 2 3

Fig 8 Occurrence of first heat period in the dog

Age of dog in days on ordinate

Group 1 on abscissa = Miniature dogs
2 = Normal sized dogs
3 = Acromegalic dogs

Each dot represents start of first heat period in one dog

CHAPTER III

Spontaneous Legg-Perthes Disease in the Dog

From 1952 through 1965 a total of 238 cases of Legg Perthes disease were collected 213 at the Royal Veterinary College in Stockholm Sweden and 25 at Ontario Veterinary College in Guelph Canada Six surgical cases were contributed by practitioners in various places in Sweden these cases were included in the Royal Veterinary College material

1 Breed Distribution

A material consisting of all cases of Legg Perthes disease presented to the Royal Veterinary College from 1952 through 1964 was used The breed distribution was compared to that in the Swedish Kennel Club registration

Toy and Miniature Poodles were considered one breed because of common cross breeding difficulties in definition of border line etc If not otherwise stated the term Poodle in tables and text does not include Standard Poodles

The artificial recognition of two different Griffon breeds was disregarded

Breeds with a sufficiently large number of dogs to show significant under representation were analyzed separately Other negative breeds were included under "Other breeds

The results are presented in Table I The table shows conclusively that Legg Perthes disease occurs *only* in miniature breeds

2 Incidence

An estimate of the incidence in the breeds in question was made by correlating the number of Legg Perthes cases (Stockholm material) against the total registration in the Swedish Kennel Club Both sets of material covered the period 1952 through 1964 These data are factual but the ratio of absolute number of Legg Perthes cases to the number presented for consultation is of course subjective

Table I Breed Distribution in Legg Perthes Disease in the Dog

	No registered in Swedish Kennel Club 195 —1964	No with Legg Perthes Disease 195 —1964	χ^2 Comparison (d.f = 1)
Miniature Pinscher	5 607	42	393 77[3]
Lakeland Terrier	1,343	15	209 21[3]
Poodle	33 895	64	88 94
West Highland White Terrier	726	6	52 66
Griffon	768	4	17 59[3]
Pekingese	7 079	14	17 26[2]
Pomeranian	1 911	6	14 37[2]
Pug	494	3	14 30[2]
Fox Terrier	6 908	12	10 95
Yorkshire Terrier	1 284	4	7 85
Chihuahua	556	2	3 46
Skipperke	229	1	0 82
Irish Terrier	297	1	0 20
Shetland Sheepdog	4,565	4	0 09
Miniature Schnauzer	1 141	1	0 08
Cairn Terrier	788	1	0 00
Scottish Terrier	1 786	1	0 02
Cocker Spaniel	11,571	4	1 78
Elkhound	12 223	0	8.35
Boxer	13 744	0	9 44
Dachsbracke	23,562	0	16 83
German Shepherd	28 897	0	20 98
Harrier	0 637	0	22.38[1]
Dachshund	55,368	6	30 99
Mongrel	—	7	—
Other breeds	56,244	0	45 37
	301 623	198	(d f = 74)

[1] 0 05>P>0 01
[2] 0 01>P>0 001
[3] P<0 001
χ^2 = χ^2 — value calculated with Yates correction

As presented in Table I Legg Perthes disease occurs only in miniature breeds. Estimates of incidence were made only in breeds significantly over represented in the material

In these breeds which included 60 105 registrations 170 cases of Legg Perthes disease occurred i e a ratio of 2 8 per 1 000 dogs

Table II Age Distribution in Legg Perthes Disease in the Dog

	Range of age at onset: months	± s.e.m.
Female dogs n = 40	4—11	7.00 ± 0.27
Male dogs n = 40	4—11	6.50 ± 0.29
Total, n = 80		7.05 ± 0.20

Difference Female — Male = 0.50 ± 0.40 t_o = 1.25 P>0.05

The important question of the ratio of all Legg Perthes cases to those presented for consultation must now be considered. About one half of the cases were from Stockholm and its immediate surroundings. It was estimated that 1 out of 4 affected dogs would be presented to the college and thus be included in the material. A range of a maximum of 1 out of 3 to a minimum of 1 out of 10 could reasonably be expected. The remaining material must necessarily be derived from a larger source. A ratio of 1 out of 10 and a range from 1 out of 7 to 1 out of 20 was judged reasonable. For the total material one thus could estimate the average to be 1 out of 7 with upper and lower limits of 1 out of 5 and 1 out of 15 respectively. The estimated incidence of Legg Perthes disease in predisposed breeds would then be 20 per 1 000 new registrations with upper and lower limits of 14 and 42 per 1 000 registrations respectively.

3 Age Distribution

The age distribution was analyzed only from cases with a reliable age given. The material included 80 cases of which 55 were collected at the Royal Veterinary College and 25 at Ontario Veterinary College.

The results are presented in Table II, which shows that Legg Perthes disease in the dog is a disease mainly of adolescence.

4 Sex Distribution

Since the sex ratio was known only in the Swedish general dog population, the Canadian material was not considered here.

There were 115 male and 98 female dogs in the Swedish material. Analysis against the general dog population showed that there is no sex predisposition for Legg Perthes disease in the dog.

Table I Breed Distribution in Legg-Perthes Disease in the Dog

	No registered in Swedish Kennel Club 195 —1964	No with Legg Perthes Disease 195—1964	χ² Comparison (d.f. = 1)
Miniature Pinscher	5 607	42	293.77[c]
Lakeland Terrier	1 347	13	209.21
Poodle	5 895	64	88.94
West Highland White Terrier	726	6	52.66[d]
Griffon	768	4	17.59
Pekingese	7 079	14	17.26[d]
Pomeranian	1 911	6	14.37
Pug	494	3	14.30
Fox Terrier	6 908	12	10.93
Yorkshire Terrier	1 284	4	7.85
Chihuahua	556	2	[illegible]
Skipperke	229	1	0.82
Irish Terrier	297	1	0.20[d]
Shetland Sheepdog	4 565	4	0.09[d]
Miniature Schnauzer	1 141	1	0.08
Cairn Terrier	788	1	0.00[d]
Scottish Terrier	1 756	1	0.02
Cocker Spaniel	11 571	4	1.78
Elkhound	12 223	0	8.35
Boxer	13 744	0	9.44
Dachsbracke	23 562	0	16.83
German Shepherd	28 897	0	20.98
Harrier	30 637	0	22.38
Dachshund	55 368	6	0.99
Mongrel	—	7	—
Other breeds	56 244	0	45.37 (d.f. = 74)
	301 623	198	

a 0.05>P>0.01
b 0.01>P>0.001
c P<0.001
d = χ² — value calculated with Yates's correction

As presented in Table I Legg Perthes disease occurs only in miniature breeds. Estimates of incidence were made only in breeds significantly over represented in the material.

In these breeds, which included 60 105 registrations, 170 cases of Legg Perthes disease occurred, i.e. a ratio of 2.8 per 1 000 dogs.

A Left and Right Side Involvement

The left side showed changes in 101 out of the 238 cases the right side in 105 Bilateral involvement was recorded in 29 cases i e 12 2 per cent

B Radiographical Classification

Although the radiographical changes in Legg Perthes disease in the dog were pathognomonic they were by no means uniform The following classification was made mainly for brief description purposes in text and legends it does not postulate any pathogenetic sequelae etc

Grade 1

In Grade 1 (Fig 9) the contour of the femoral head and neck was normal The joint space was clearly widened Single or multiple foci of decreased density occurred in the head and more rarely in the neck just distal to the epiphyseal line

The acetabulum appeared normal

Grade 2

As those in Grade 2 (Fig 10) were classified cases with flattening of the head clearly visible With this grade as well as in subsequent ones there was no further increase in the joint space More numerous and larger foci of decreased density caused a moth eaten appearance This was not restricted to the head but occurred in the neck as well Involvement of the neck occurred in all subsequent grades

The antero-lateral aspect of the acetabular rim often showed a small spur

Grade 3

Contour disturbances were more accentuated in Grade 3 (Fig 11) than in Grade 2 There was a moderate to pronounced impression of the femoral head with irregular indentations on the articular surface The moth-eaten appearance persisted

The acetabular spur formation might be more pronounced in this grade and in the subsequent ones

Grade 4

In Grade 4 (Fig 12) the normal outline of the head was completely lost Minor fragmentations belonged to the picture Confluence of enlarged areas of decreased density dominated the appearance Normal density occurred only in haphazardly distributed islands

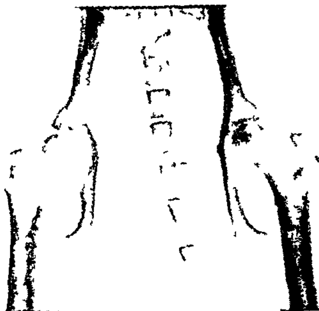


Fig 9 Poodle female 1 year old Radiographical change Grade 1 right side Widening of joint space normal contour of femoral head density slightly irregular



Fig 10 Fox Terrier female 7 months old Radiographical change Grade 2 right side Flattening of femoral head moth eaten appearance of head and neck slight spur formation on acetabular rim



Fig 11 Pug female 6 months old Radiographical change Grade 3 left side Impression of femoral head in addition to changes of Grade 2



Fig 12 Pekingese male 9 months old Radiographical change Grade 4 left side Loss of contour of femoral head confluence of radiolucent areas

Fig 13 Australian Terrier male 9 months old Radiographical change Grade 5 left side Fragmentation of femoral head in addition to changes of Grade 4



Fig 14 Fox Terrier female 8 months old Legg Perthes disease Grade 3 on right side Diffuse increase of density of left femoral head and neck Not increased density lateral to margin of acetabular roof

Grade 5

Extensive fragmentation of the femoral head and thus discontinuity of the articular surface were the characteristics of Grade 5 (Fig 13)

Changes in the acetabulum were still more pronounced than in Grade 4

The five grades just described refer to clinically manifest cases of Legg Perthes disease In a number of cases radiographical changes were demonstrated on the contralateral clinically healthy side This change consisted of a diffuse increase in the radiographical density as shown in Fig 14 None of the changes of Grades 1 through 5 were evident

C *Correlation Between Radiographical and Clinical Pictures*

The results are presented in Table III

As seen from the table there was a trend toward increase in the degree of radiographical change with increased chronicity of clinical signs The great range of material made this observation of limited value for the individual case

Similar observations were made concerning the correlation between the radiographical appearance and degree of lameness

D *Course of Radiographical Changes*

The results will be presented under 7 *Treatment*

Table III Correlation Between Radiographical Changes and Clinical Symptoms in Legg Perthes Disease in the Dog

	Degree of rad g aphical change 1 n = 9	n = 13	3 n = 0	4 n = 15	5 n = 11
Duration of lameness days Range	2—150	2—60	14—180	14—360	1—180
$\bar{x}$ ± s e m	32±15	41±7	66±11	107±26	83±18
D gree of lameness Range	1—5	1—5	1—5	1—5	3—5
$\bar{x}$ ± s e m	3 2±0 5	2 8±0 4	4 0±0 2	3 6±0 4	4 3±0 3

D gree of lameness according to conventional classification from 1 = slight limping to 5 = complete disuse of leg (three legged lameness")

Table IV Results of Treatment in Legg Perthes Disease in the Dog

	Conservative treatment n = 6	Surg al t eatment n = 39
Recovery p r cent	24	85
Recovery within two months per cent	6	64
No recovery per cent	76	15

7 Treatment

The results of different treatments are summarized in Table IV

A Conservative Treatment

Conservative treatment included rest or limited exercise and in some cases medications with vitamins or drugs for pain relief

Evaluation of results of conservative treatment was based on information from 62 owners Observation periods ranged from one to eight years Radiographical follow up studies were made in 25 cases with intervals ranging from one month to more than three and one half years

Complete recovery was reported in 15 out of 62 cases Only 3 cases had recovered within 2 months after onset of lameness In 11 cases euthanasia was requested at varying times because of poor response to treatment The remaining dogs continued to show lameness and pain Many owners said signs were accentuated in cold and wet weather

Table 1   Course of Radiographical Changes with Conservative Treatment

First observation		Follow-up observations	
Age of dog months	Degree of radiographical change	Age of dog months	Degree of radiographical change
3	0	9	4
		13	4
		24	4
6	0[1]	8	0
		14	4
7	0	8	4
		13	4
8	0	10	1
		11	2
		12	2
		16	5
9	0[1]	10	1
		43	2
		52	2
3	1	12	3
5	1	7	3
6	1	9	4
6	1	8	2
		38	5
8	1	9	3
9	1	10	2
10	1	12	3
		13	3
		16	3
6	2	29	5
7	2	8	
12	2	17	2
		20	2
		25	3
8	3	9	5
8	3	9	5
8	3	42	5
9	3	21	5
10	3	16	3
12	3	16	5
12	3	18	
6	4	8	5
		12	5
7	4	8	5
21	4	26	4

[1] Case diagnosed during follow up of surgery on opposite side

The radiographical changes grew worse in 22 out of 25 cases and on *none of the cases* was there an improvement (Table V)

The radiographical sequelae are exemplified in Figs 15 through 17

B Surgical Treatment

Excision arthroplasty according to Spreull (1961) was performed under spinal nerve block supported by tranquilization in 89 cases Bilateral cases were operated on on both sides in the same session or with an interval of a few days The patients were hospitalized in cages for 3 days after surgery External fixation for immobilization of the operated leg was not used and the dogs were allowed limited exercise Skin sutures were removed after 10 days and the owners were told to force their dogs to use the operated leg

Follow up studies were possible on 39 surgical cases from the Royal Veterinary College Three of these were operated on bilaterally

The dogs were considered recovered when all signs of pain and lameness had disappeared and full weightbearing was resumed A slight or moderate muscle atrophy or visible shortening of the operated leg were disregarded Special attention was given to the dogs ability to jump and climb stairs

Post operative observation time ranged from 4 months to 5 years

Out of the 39 cases 25 recovered within 2 months after surgery

The following cases show to what extent physical ability can be restored A Dachshund was used for hunting 9 months following unilateral excision arthroplasty Another Dachshund was bred accidentally 5 months after surgery and the operated leg adjusted well to the increased weight bearing during pregnancy This dog was also used for hunting later on A Miniature Pinscher with bilateral surgery and a Griffon with unilateral resection were subsequently used extensively as studs The Griffon also made an excellent show career after surgery

Euthanasia was performed for other reasons on two dogs reported recovered 3 and 7 months respectively after surgery The remaining 6 dogs continued to show varying degrees of lameness The observation period in these cases ranged from 5 months to 3 years In none of the cases however was the condition considered more crippling after surgery than before

In all operated dogs abduction was markedly limited but there was no pain on passive movements of the hip

Fifteen surgical cases were followed radiographically The ages of the dogs at surgery ranged from 5 to 18 months All cases except two were operated on when first diagnosed and the remaining cases after a delay of 1 and 8 months Follow up studies were made for periods as long as four and one half years

Surgery always resulted in persistent dorsolateral displacement of the proximal end of the femur In radiograms with legs in stretched position the rem

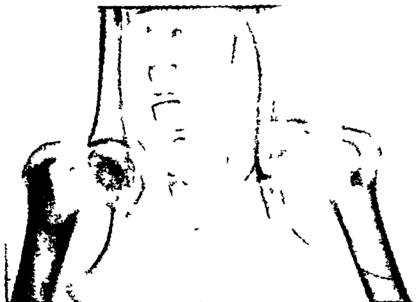


Fig 15 A Poodle male 8 months old Presented for lameness Widened joint space on left side otherwise normal hip joints

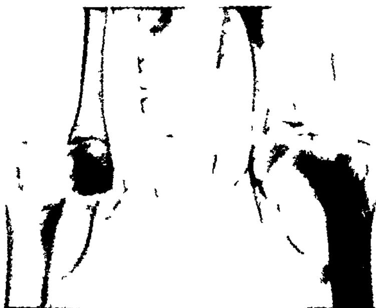


Fig 15 B Same dog as in Fig 15 A 1 month later Radiographical change Grade 3 of left hip joint



Fig 16 A Fox Terrier male 7 months old Radiographical change Grade 3
Fig 16 B Same dog as in Fig 16 A 1 year later Severe degenerative arthrosis



Fig 17 A Poodle female 8 months old Radiographical change Grade 2
Fig 17 B Same dog 3½ years later Severe degenerative arthrosis malformation of femoral head and neck exostoses on acetabulum

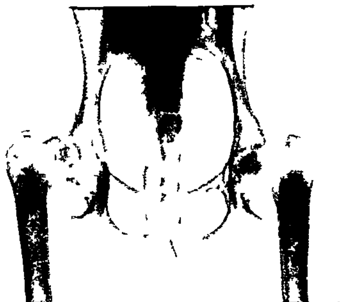


Fig 18 A Miniature Pinscher male 8 months old Bilateral Grade 5 Legg Perthes disease Note severe fragmentation on both sides



Fig 18 B Same dog 7 days after resection of right femoral head



Fig 18C Same dog one year after bilateral resection arthroplasty Femoral stump on both sides located dorsolaterally to acetabulum Contour of greater trochanter still rather well defined Exostoses on acetabular rim

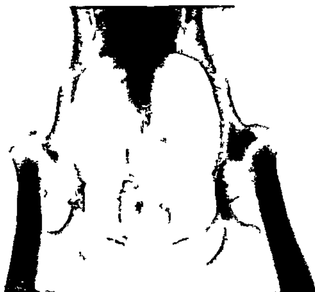


Fig 18D Same dog 4½ years after surgery Topography same as in Fig 18C Contour of greater trochanter blends diffusely with remnants of femoral neck to give a rounded outline Acetabular exostoses more extensive

nant of the femoral neck appeared riding on or located dorsolaterally to the acetabular rim

In early follow up radiograms—from 7 to 30 days—the contours of the greater trochanter and the resection line were sharply defined A rounding of the trochanter with a diffuse loss of its contour and smoothening of the resection line gradually occurred In two cases followed for more than three years the contour of the proximal end of the femur appeared club shaped and regular

Exostoses around the acetabular rim defined as part of the untreated Legg Perthes case progressed to moderate but rarely severe degrees In advanced stages the acetabulum appeared flattened This apparently resulted from grinding of the acetabular rim by the femoral stump with concomitant adjacent osteophytosis

The radiographical sequelae are shown in Figs 18 A through 18 D

Three dogs were necropsied at 4 10 18 months following excision arthroplasty In the first two cases the round ligament had attached to the medio-proximal side of the femur The joint capsule was markedly thickened about three mm the synovial fluid appeared normal The femoral stump was covered with fibrous tissue In the third case no joint capsule or synovial fluid was visible Instead there was a fibrous connection between the femoral stump and the acetabular cavity

8 Pathological Anatomy

A Conventional Morphological Examination

The surgical specimens from 82 cases 4 of which were bilateral were examined macro and microscopically The specimens were fixed in 10 per cent neutral formalin after midsagittal sectioning on a bandsaw Only one half of the femoral head was used for histopathology in cases where micro-radiography also was employed Demineralization in 5 per cent nitric acid was used in about 70 cases Ten per cent formic acid as described in Chapter II was used in the remaining cases Paraffin embedding and sectioning at 6 microns were employed Hematoxylin and eosin (H&E) was used in all cases Toluidine blue staining for evaluation of the metachromasia associated with osteolysis (Belanger *et al* 1965) was used in 57 cases

Necropsy was performed in 2 cases

Determination of skeletal maturation was carried out in 18 cases of suitable age as described in Chapter II



Fig 19 Lakeland Terrier female 8 months old Lameness for 2 months Infolding of articular cartilag and slight deformation of femoral head of affected side

a Macroscopical morphology

Femoral head The macroscopical appearance of the resected specimens varied considerably In mild cases the shape was normal and the changes were limited to occurrence of large areas in the articular cartilage which exhibited a brownish blue color diffusely demarcated against the normal greyish white background The mid sagittal cut surface showed that this resulted from irregular thinning of the articular cartilage

In more advanced cases contour disturbances were added to the picture A flattening would affect mainly the dorsal aspect of the head hence the head became more cone shaped with the round ligament at the top In other instances the flattening would concern the top of the head with the ligament in the center of the impression The cartilage of the impressed areas usually showed irregular infoldings or a roughening of the surface (Fig 19) The mid sagittal cut surface sometimes showed a grey yellow brown mottling

In severe cases there was fragmentation of the head Complete detach ment of minor pieces was seen in only one case three pieces completely covered with cartilage were found attached to the torn round ligament Otherwise fragmentation was apparent only following mid sagittal sectioning The articular cartilage with a thin layer of bone was detached from the osseous head by means of a subchondral dissecting pouch In addition the cut



Fig 20 Skipperke female 9 mounth old Wide area of calcified cartilage Very thick trabeculae H&E x 120

surface exhibited minor but numerous cracks on the mottled background In extreme cases sectioning of the femoral head resulted in pulverization of the osseous structures

The morphology of the epiphyseal growth plate will be accounted for under microscopical morphology

Examination of the *round ligament* and the *joint capsule* was difficult during surgery There appeared to be no major changes with the aforementioned exception of that of the round ligament

The amount of *synovia* appeared to be normal the synovia never poured out forcefully upon incision of the joint Color and viscosity were normal and flocculation was never observed

b Microscopical morphology

Skeletal maturation

The time of closure of the proximal growth plate of the femur is illustrated in Fig 1 (Chapter II) Statistical analyses proved



Fig 21 Same dog as in Fig 20 Compact bone with well defined osteons in epiphysis H&E x 180

1 Closure of the proximal epiphyseal growth plate of the femur occurred at the same time in dogs with Legg Perthes disease as in normal miniature dogs
2 Closure of the growth plate occurred at a significantly earlier time in dogs with Legg Perthes disease than in non affected normal sized dogs
3 Time period involved in closure processes was the same in dogs with Legg Perthes disease as in non affected miniature dogs and in normal sized dogs

Histopathology of Legg Perthes disease

Three main types of lesions were typical of Legg Perthes disease in the dog viz excessively thickened epiphyseal and metaphyseal bone necrosis of bone marrow and bone tissue proper and reparative phenomena

The earliest change was increased thickening of epiphyseal and metaphyseal trabeculae (Fig 20) Relatively large osteoblasts usually lined the epiphyseal trabeculae in a single layer whereas osteoblastic activity was still more

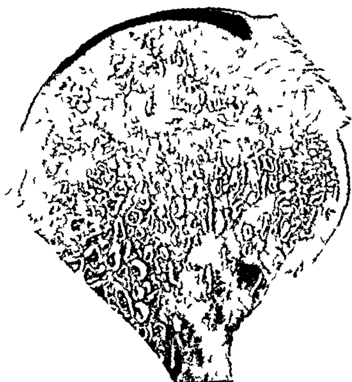


Fig 23 Fox Terrier female 8 months old Compact bone of almost entire epiphysis and metaphysis Growth plate completely closed H&E direct enlargement of slide × 6 0

pronounced in the metaphysis The trabeculae were not only widened in the sections but there was also true osteon formation with easily recognizable Haversian lamellae and canals (Fig 21) These changes were found *consistently* at the junction between the articular cartilage and bone The zone of calcified cartilage was markedly widened (Fig 20) These entities increased amount of bone and faulty remodelling would be extensive enough to give the entire section the appearance of homogeneous compact bone (Fig 22)

Further evidence for the chronology of events was obtained from the following case In one dog with radiographically diagnosed unilateral Legg-Perthes disease the opposite femoral head was excised by mistake In this specimen pathologically increased amounts of trabecular bone was the only change

Toluidine blue metachromasia around deep seated osteocytes of thickened trabeculae and Haversian lamellae was normal for age The increased amount



Fig 23 Poodle male 9 months old Marrow necrosis with fragments of necrotic bone in epiphysis H&E x 150



Fig 24 Chihuahua male 10 months old Osteon like configuration with small central necrosis at straight arrow marrow necrosis with dead bone spicule at curved arrow H&E x 120



Fig 25 Poodle male 12 months old Small necrosis in excessively thickened calcified cartilage at arrow Large marrow necroses H&E x 120

of bone therefore could be explained only by excessive formation and *not* by decreased osteolysis

The increased formation of bone referred to endosteal bone only The periosteal osteoblastic activity was not influenced

The uncomplicated picture just described was a rare finding — it was recorded in 6 out of 82 cases In 2 of these cases serial sectioning of the paraffin block (i e half the femoral head the other half was used for microradiography) failed to reveal changes in 310 slides in one case whereas in the other case there were minor areas of necrosis fibrosis and osteoclasia in the peripheral 110 out of 240 sections

In the next stage necrosis of the femoral head entered the picture It concerned both bone marrow and bone tissue proper Marrow necroses appeared as structureless bluish (H&E) poorly demarcated areas sometimes of impressive size Bone fragments or spicules were often trapped in these necroses (Fig 23) Such bone was likewise necrotic the osteocytic lacunae were void of cells or would contain cells with pyknotic nuclei



Fig 26 Poodle male 10 months old Collision of laterally expanded trabeculae with extensive osteonecrosis Fibrous reaction against necrosis in lower part of figure H&E x 120

Necroses of bone tissue proper also occurred without immediate relation to marrow necroses

One site of predilection appeared to be the center of osteons resulting from faulty remodelling (Fig 24) In such cases the innermost lamellae would be disrupted with acellular fragments scattered in structureless debris Necroses also occurred haphazardly in areas of excessively thickened bone (Fig 25)

Osteonecrosis also occurred from collision of laterally expanded trabeculae A large area of microfractures and necrosis from such collision is depicted in Fig 26

Osteonecrosis was very common just below the junction between articular cartilage and epiphyseal bone (Fig 25) It would occur in solitary areas in the thickened bone but confluence of adjacent osteonecroses often resulted in large subchondral pouch formation (Fig 27) This dissecting osteochondrosis was the anatomical basis for the detachment of the articular cartilage as observed macroscopically



Fig 31 Shetland Sheepdog male 11 months old Transversal fissure in growth plate Extensive fibrosis of epiphysis and metaphysis with severe distortion of growth plate H&E x 45

With minor necroses including subchondral ones the contour of the head would remain normal More extensive osteonecrosis was combined with distortion of the contour It ranged from moderate and diffuse flattening to irregular and extensive infoldings (Figs 28 29) Areas of quite large hemorrhages would accompany these acute changes (Fig 27) When present the growth plate would also be the object of such distortion and displacement

In addition to the changes associated with closure the epiphyseal growth plate often but not consistently showed transversal fissures They would appear at any level of the growth plate but seemed to be more prevalent in the widened zone of resting cartilage (Figs 30 31) The borders of the fissures were either smooth or fibrillar the latter finding precluded sectioning artifacts

Reparative changes included fibrosis osteoclastic resorption and apposition of bone



Fig 32 Poodle male 12 months old Early fibrous reaction against marrow and bone necroses H&E x 120

Fibroplasia as a reaction against necrosis of bone marrow and bone tissue proper first appeared in intact bone marrow (Fig 32) It should be emphasized that this response was *localized* and *not* a result of ingrowth of vessels from the periphery with concomitant proliferation of fibrous tissue Serial sectioning of the block from which Fig 32 was derived showed conclusively that fibroplasia occurred at the site of necrosis It disappeared after a few sections New minor necrosis would then appear in subsequent slides each with its *localized* fibrous reaction

In early cases the fibrous replacement would be inconspicuous but in later ones the fibrous tissue would replace the necroses entirely At the border line between fibrous tissue and dead or dying bone a varying number of osteoclasts would appear Sometimes they were located in Howship s lacunae In other areas however they were trapped in the fibrous tissue in large conglomerates (Fig 33) Osteoclasia appeared to be the only mode of resorption of dead or dying bone osteolysis evidently did not participate



Fig 33 Poodle male 12 months old Osteoclastic resorption of bone at upper part of figure Large accumulation of inactive osteoclasts in center of fibrotic area H&E x 120



Fig 34 Shetland Sheepdog 11 months old Fibrous reaction against necrosis at straight arrow Osteoblasts lining most trabecular surfaces Osteoclasia at curved arrows H&E x 120



Fig 35 Poodle male 9 months old Head of humerus Same dog as in Fig 28 Excessively thickened epiphyseal trabeculae H&E x 45 Compare Fig 35 with Fig 20 of femoral head

In spite of the hemorrhages observed with acute necrosis there was no hemosiderosis of macrophages in the fibrous tissue at this time

Cyst like formations in the fibrous tissue were sometimes observed (Fig 29) They were occasionally visible with the naked eye on the section They were lined by a dense fibrous tissue and empty

Disrupted and dislocated fragments of invaginated articular cartilage and/or of the growth plate were sometimes found surrounded by fibrous tissue (Fig 31)

Bone apposition occurred in the fibrous tissue (Fig 34) Osteoid formation by osteoblasts would appear as tiny islands Any intermediate stage to the occurrence of relatively thick anastomosing trabeculae was also present Usually such trabeculae exhibited a well defined osteoid seam covered by large osteoblasts sometimes even in multiple layers

The thickness of the articular cartilage varied within wide ranges (Fig 29) Sometimes it would measure only a few cell layers but more commonly it



Fig 36 Poodle male 9 months old Distal metaphysis of femur Acute osteone crosis H&E x 120 Femoral head depicted in Fig 28

was immensely thickened These extremities would occur within one and the same section

Restoration of the contour was not achieved by means of the reparative processes just described The subchondral dissecting pouches were not closed in any specimens examined even though fibrosis and bone apposition were pronounced in other areas

Necropsy material

In two cases presented with the usual anamnesis radiographical examination revealed bilateral Legg Perthes disease Euthanasia was performed at the owner s requests

Midsagittal sections of the proximal and distal ends of long bones and of the first lumbar vertebra were examined Serial sectioning was not employed

Histologically both femoral heads of the two cases showed long standing changes of Legg Perthes disease *Excessive endosteal bone formation was*

evident throughout the skeleton Only minor necroses without reaction were found occasionally Premature closure of epiphyseal growth plates was generalized Figs 35 and 36 exemplify changes from the necropsy material

B Microradiography and

C Tetracycline Labelling

Tetracycline labelling was performed in 43 cases A dose of 25 mg per kg bodyweight of a tetracycline (chlortetracycline hydrochloride or tetracycline hydrochloride) was injected intravenously 24 hours before surgery

Half of the surgical specimen was fixed in absolute alcohol for several days with frequent changes to fresh fixative After embedding in metamethylacrylate the specimens were sawed ground down to about 100 microns and radiographed according to the procedure described by Soennacs (1947) Bergendahl & Engfeldt (1960) Hallen & Rockert (1960) and Eriksson (1965) as summarized and modified by Olsson & Rietz (1966)

Microradiographical examination proved valuable in demonstrating architecture amount and density of bone Microradiographical morphology is illustrated in Figs 37 and 38

With *tetracycline labelling* active mineral deposition was depicted (Urist & Ibsen 1963) It thus demonstrated the anabolic processes during the last 24 hours

1 at the calcifying zone of the articular cartilage
2 on epiphyseal and metaphyseal trabeculae and
3 on osteoid laid down by osteoblasts in the osseous metaplasia of the reparative fibrosis

Tetracycline fluorescence is illustrated in Figs 37 and 38

9 Discussion

The discussion in this chapter will be limited to the interpretation of the pathological anatomy with the ultimate purpose of formulating an etiological hypothesis

A Pathogenesis

The earliest change in the femoral head in Legg Perthes disease in the dog appeared to be excessive endosteal bone formation Abnormally thick trabeculae *in the epiphysis and metaphysis was the only lesion in a number of* surgically removed specimens In one dog with radiographically diagnosed

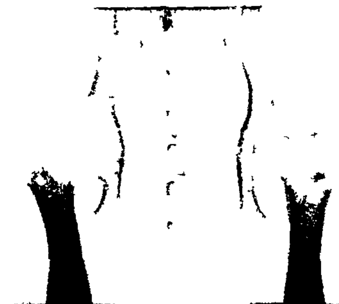


Fig 37 Poodle male 2½ months old (This case was examined in 1966 It is not included in the material on age distribution in which 4 months was given as lower limit) Presented for lameness of 2 days duration

Fig 37 A Radiogram showing dissecting subchondral pouch laterally on right femoral head



Fig 37 B Radiogram 10 days later Change of Fig 37 A superimposed by area of decreased density on both sides of epiphyseal line



Fig 37 C Microradiogram of 100 microns thick specimen Large dissecting pouch below calcified cartilage and a few epiphyseal trabeculae Microfractures of thickened epiphyseal trabeculae Metaphyseal trabeculae still wider In lower left part of specimen complete lack of radiopaque structures cf radiogram cf Fig 37 B x 9



Fig 37 D Same specimen as in Fig 37 C photographed with transmittent ultra violet light Tetracycline (injected 24 hours before surgery) fluorescence of calcifying one of articular cartilage and in metaphysis especially of primary spongiosa Note the absence of labelling of the epiphyseal trabeculae and the debris between them cf Figs 37 C and 37 E x 9



Fig 37 E Detail of Fig 37 D x 2



Fig 37 F Photomicrograph of adjacent part of opposite half of femoral head Subchondral dissecting pouch large epiphyseal necrosis (empty space) H&E x 9

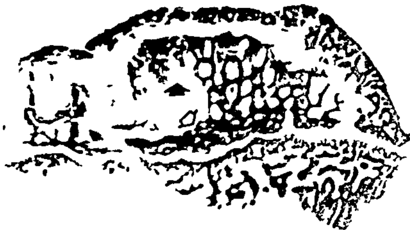


Fig 38 Australian Terrier male 7 months old Lameness for 2½ months
Fig 38 A Microradiogram of 100 microns thick specimen Large radiolucent area below calcified cartilage with a few trabeculae Large mass of extremely thickened trabeculae in epiphysis At left of mass a large cavity x 10





Fig 38 B Detail of area in front of filled arrow in Fig 38 A Numerous fractures of thickened trabeculae x 25



Fig 38 C Detail of area in front of unfilled arrow in Fig 38 A Howship's lacunae indicating resorption at straight arrows newly formed bone at curved arrow × 100



Fig 38 D Same specimen as in Fig 38 A photographed with transmittent ultra violet light Tetracycline (injected 24 hours before surgery) fluorescence of calcifying articular cartilage Fluorescence of great intensity in primary spongiosa otherwise moderate in metaphysis Reparative bone formation in periphery of necrosis indicated by intense fluorescence Note complete absence of tetracycline uptake in large bone mass in epiphysis × 10

unilateral Legg Perthes disease the opposite femoral head was excised by mistake In this specimen pathologically increased amounts of trabecular bone was demonstrated upon histological and microradiographical examinations In the other head the sam changes were superimposed by necrosis and reparative processes These findings confirm the interpretation that excessive endosteal bone formation constitutes the initial morphological change in Legg Perthes disease

Necroses of bone marrow and bone tissue proper were next to appear The pathogenesis of marrow necrosis was not elucidated by histological examination With regard to osteonecrosis the microscopical picture was more informative

When marrow necroses were extensive and completely surrounded trabecular bone osteonecrosis also occurred Although this finding was quite common osteonecrosis unrelated to marrow necrosis was observed more frequently The accelerated bone apposition resulted in continuous lateral expansion of trabeculae The inevitable result of this was a collision of adjacent trabeculae Necrotic spicules and fragments represented the wreckage on the scene and necrosis was also the fate of the colliding trabeculae

Large areas of dense bone often with osteonlike configurations likewise exhibited necrosis The site of predilection was the innermost lamellae of Haversian like systems but they would occur anywhere in the bony structure The explanation of their pathogenesis remained theoretical It would be reasonable to assume that this faulty remodelling would also include faulty blood supply to the abnormally structured bone The necrosis would then result from local interference with nutrition on or beyond the capillary level The resemblance of central necrosis which may occur with the growth of an osteoma appears to be not too far remote

Resorption of necrotic bone occurred through osteoclasia alone This is in agreement with a statement by Belanger *et al* (1965) that "Osteoclasia appears as a specialized response to the presence of abnormal skeletal material either of general or local origin Osteolysis played no part for the obvious reason that this type of resorption requires mature highly active osteocytes

Repair of marrow necroses and replacement of resorbed necrotic bone occurred through *localized* fibrous reaction Rebuilding of trabeculae in the fibrous tissue occurred in the usual way viz osteoid apposition by osteoblasts differentiated *in situ* from more immature connective tissue cells

Cyst formation in the fibrous tissue was rare Too few cases were observed to allow statements on the pathogenesis There is no reason however to believe in difference from the usual patterns in cyst formation Distortion of the fibrous tissue results in capillary extravasations the blood is hemolyzed further hemorrhages occur into the area and the surrounding tissue is pushed peripherally The cyst wall therefore consists of densely packed fibrous cells

The effect of estrogen on endosteal bone formation was demonstrated by Gardner & Pfeiffer (1938) The action of sex hormones on bone and bones has been the object of extensive reviews by Weinmann & Sicher (1955) and by *Silberberg & Silberberg (1956) inter alia Species differences in response* to injections of sex hormones are well known In mice the response is dramatic but there is no effect on endosteal bone formation in the rat (Urist *et al* 1948)

Longitudinal skeletal growth from epiphyseal growth plates is controlled by the somatotrophin This is the very definition of growth hormone If sex hormones appear on the scene prematurely they will counteract the somatotrophin universally Mitotic division of resting cartilage cells of the growth plate is arrested growth ceases and closure of the epiphyseal growth plate eventually occurs

The pathophysiological and morphological sequelae interpreted as the fundament of Legg Perthes disease in the dog would require premature appearance of the first heat period as an external sign of precocious sexual maturity in breeds predisposed to the disease This was also shown to be the case

Hypergonadotrophism

Precocious sexual maturity would require precocious stimulation of the gonads by means of too early action of the gonadotrophins This in turn would require an imbalance between the gonadotrophin producing delta cells of the basophils in the anterior pituitary gland and the somatotrophin producing acidophils in favour of the former ones (terminology according to Ham 1965) Histological studies to support such a theory have not been reported in available literature On the other hand Stockard (1941) claimed that in acromegalic dogs the pituitary cell population was overwhelmingly dominated by acidophils Such a morphological picture would indicate imbalance between somatotrophin and gonadotrophin production It seems to be more than a coincidence that the investigations on the occurrence of the first heat period (Fig 8) showed that it did occur significantly later in acromegalic dogs

10 Formulation of a Hypothesis on the Etiology

The present study and discussion of Legg Perthes disease in the dog led to the formulation of the following hypothesis on the etiology

THE MORPHOLOGICAL PICTURE OF LEGG PERTHES DISEASE IN THE DOG IS A MANIFESTATION OF PRECOCIOUS SEXUAL MATURITY

The hypothesis was tested experimentally as reported in the following chapter



Fig. 59. Beagle female treated with estrogen for 56 days. Head of femur. Articular cartilage narrowed but with wide calcified zone below line at arrow. Trabeculae extensively thick. H&E. × 120.

Midsagittal sections were prepared of proximal and distal ends of all long bones. The first lumbar vertebra was likewise sectioned. Formic acid demineralization was employed; otherwise the same histological methods were used as before.

2. Results

A. Clinical Symptoms

Body weight gain was not influenced by treatment.

A male Beagle treated with testosterone for a total of 71 days showed a pronounced hind leg lameness for the last few weeks before euthanasia. In other experimental dogs no lameness was recorded. Possible signs of locomotor disturbance may have been obscured by the creeping or crawling gait typical of cage-kept young dogs.

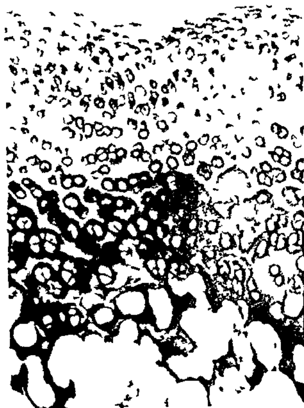


Fig 40 Female litter mate control ♀ dog of Fig 39 Same area stain and magnification Note thickness of articular cartilage and thin trabeculae

Male dogs exhibited constant libido after three to four weeks on testosterone treatment

Progressive enlargement of the mammary glands and external genital organs were observed in dogs of both sexes regardless of treatment The facial bones were slightly retracted and the dogs looked aged and worried The hair coat appeared dull

B Radiography

Already after four weeks of treatment the height of the proximal epiphyseal line of the femur was markedly reduced in treated dogs This difference between test animals and controls was further accentuated with increased duration of experiment Complete closure was however not reached during the experiment

Radiographical changes previously described typical of Legg Perthes disease were not recorded at any stage

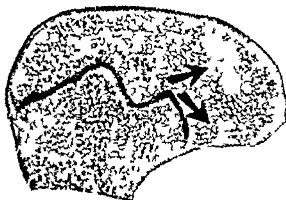


Fig 41 Beagle male treated with testosterone for 71 days Head of humerus Large areas of compact bone (arrows) in epiphysis H&E direct enlargement of slide × 2 8



Fig 42 Beagle female treated with estrogen for 56 days Head of femur Almost complete eburnation of articular cartilage Large marrow necrosis in front of straight arr[illegible] [illegible]like formations at curved arrows H&E × 120



Fig 43 Same dog as in Fig 4? Proximal fem ral epiphysis In center of figur marrow necrosis with dead bone fragment Collision of expanding trabeculae at arrow crushed fragments between trabeculae H&E x 1?0

C Pathological Anatomy

Macroscopical morphology

The brownish blue discoloration of the articular cartilage described in early cases of Legg Perthes disease occurred in the femoral head of experimental dogs from 56 days or more Localized total eburnation of the articular cartilage was found in one case (Beagle female treated with estrogen for 56 days) Other bones revealed no changes

The gonads were strongly hypoplastic Uterus of female dogs was markedly enlarged Glandular hyperplasia of the prostate in male dogs was severe with the most dramatic changes resulting from estrogen treatment

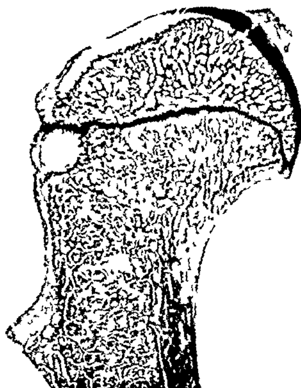


Fig 44 Beagle male treated with testosterone for 139 days Head of femur Subchondral osteonecrosis with pouch formation Eburnation of articular cartilage Note thickness of epiphyseal trabeculae Large empty necrosis in metaphysis H&E direct enlargement of slide = 4 0

Microscopical morphology

The description will concern only the skeleton

Skeletal maturation The difference in morphology of the growth plates between treated and control animals was very evident after 32 days (the earliest day of euthanasia) The plate was markedly narrower in treated animals and the differentiation was considerably retarded The resting cartilage zone was disproportionately wide The columnar and vesicular cell zones were not only narrower but also less densely packed with cell rows

The changes progressed Following the longest treatment 139 days the proximal epiphyseal growth plate of the femur was only a few cell layers thick with several perforations Growth plates of other bones including vertebrae showed similar changes with the variations resulting from normal earlier or later closure



Fi 45 Same dog as in Fig 44 Distal humerus Osteochondrosis dissecans with internal aspect of detached cartilage covered with thin layer of bone Note thickened trabeculae and osteon like configurations H&E x 30

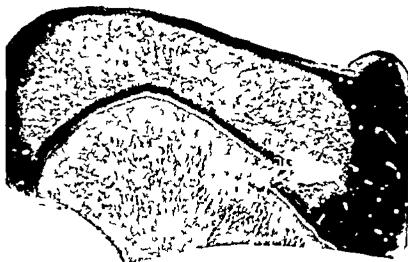


Fig 46 German Shepherd treated with testosterone for 32 days Head of humerus Large epiphyseal and metaphyseal necroses with disruption of growth plate H&E direct enlargement of slide = 2 8

Histopathology of skeleton The site of predilection for excessive bone formation was the junction between articular cartilage and bony epiphysis The changes occurred in all bones The zone of calcified cartilage was markedly widened and epiphyseal trabeculae excessively thickened These changes were clearly visible in the dog killed after 32 days and increased continuously with increased experimental time The changes that occurred after 56 days are illustrated in Fig 39 Fig 40 shows the normal morphology in an untreated litter mate of the same sex

Excessive apposition of bone resulted in formation of large areas of compact bone with osteons as illustrated in Fig 41 from a male Beagle treated with testosterone for 71 days

Osteolysis as demonstrated by toluidine blue metachromasia was of the same intensity in bone slides from test and control animals

As with spontaneous cases of Legg Perthes disease necroses occurred in bone marrow and in bone tissue proper The marrow necroses with fragments or spicules of dead or dying bone were identical to those described in spontaneous cases They are illustrated in Figs 42 and 43 Necrosis of bone tissue proper occurred in the center of osteon like formations Such necroses would involve only the innermost lamellae or most of the osteon (Fig 42) Osteonecrosis also occurred as a result of collision of laterally expanding adjacent trabeculae (Fig 43) Acellular fragments therefore would be found pinched between such lamellae (Fig 43) Microfractures of thickened and irregular trabeculae occurred with or without associated necrosis (Figs 42 43 44)

As with excessive bone formation necrosis was found throughout the skeleton However necrosis had a definite site of predilection in the femoral head Subchondral necroses were the rule and confluence resulted in large dissecting pouches (Fig 44) The covering cartilage exhibited varying degrees of necrosis and sloughing (Figs 42 44) As in spontaneous cases of Legg Perthes disease metaphyseal necroses occurred as well and would reach impressive dimensions (Fig 44)

The generalized skeletal response is further illustrated in Figs 45 and 46 In Fig 46 there are extensive necroses in the epiphysis and in the corresponding area of the metaphysis Both the proximal and distal osseous support for the growth plate is lost hence the growth plate is disrupted

Reparative processes were never encountered in the experimental material

3 Discussion

The initial morphological changes in spontaneous cases of Legg Perthes disease viz. excessive endosteal bone formation and premature closure of the growth plates were reproduced experimentally in juvenile dogs of breeds constitutionally resistant to the spontaneous disease The hypothesis formulated that the morphological picture of Legg Perthes disease in the dog is a manifestation of precocious sexual maturity thus was proven valid

The pathogenesis of the excessive amounts of endosteal bone was identical in spontaneous and experimental Legg Perthes disease Increased amounts of endosteal bone can result either from increased formation or decreased resorption of bone Both possibilities have been discussed in experimental hyperestrogenism as reviewed by Silberberg & Silberberg (1965) Those favoring decreased resorption have based their opinion on decreased osteoclastic resorption (Urist *et al* 1948) It is now known that osteoclastic resorption is of far less importance than osteolysis in both normal remodelling and in the accelerated resorption typical of hyperparathyroidism (Belanger *et al* 1965 Gries 1966 Brown *et al* 1966) Evaluation of resorption rate in hyperestrogenism based on the number of osteoclasts which already is insignificant under normal conditions is too superficial Osteolysis is most easily demostrated by the toluidine blue metachromasia that occurs in the bone matrix around mature osteocytes at maximal distance from the apposition surfaces Osteolysis was normal both in spontaneous and experimental Legg Perthes disease The increased amounts of endosteal bone therefore must be due to excessive apposition

The pathogenesis of osteonecrosis was the same in spontaneous and experimental Legg Perthes disease Collision of laterally expanding trabeculae was a prominent feature in both materials

As with spontaneous cases of Legg Perthes disease accelerated endosteal bone formation was generalized in experimental dogs The degree was however far greater in the experimental cases It seems obvious that this was a direct result of the large doses employed This was evident by the violent manifestations of the secondary sex characteristics

Estrogen and testosterone produced the same lesions These findings are direct contradictions to statements by Urist *et al* (1948) and by McLean & Urist (1961) that endosteal bone formation is not influenced in puppies and dogs following estrogen injections

The skeletal changes in both spontaneous and experimental Legg Perthes disease in the dog are generalized but the femoral head is the outstanding site of predilection Although a clear-cut explanation can not be given for this predilection a few possibilities will be discussed

It has been shown that the skeletal response to estrogen injections is universal but not uniform and varies with species (Urist *et al* 1948 Silberberg &

Silberberg 1956) The femur is high or highest on the list of susceptible bones Urist *et al* (1948) attempted to explain this as related to the large growth capacity of that bone

Mechanical factors must also be considered The mechanical pressure on the front legs is greater than on the hind legs in quadrupeds The mechanical forces are transmitted in vastly different ways in the shoulder and pelvic girdles In the dog the shoulder is attached to the thorax by soft tissues alone with a sparing effect of this spring suspension on the bones and joints of the fore limb In the hip joint on the other hand the mechanical stresses are transmitted directly onto the femoral head

The reparative processes seen in later stages of spontaneous Legg Perthes disease were not observed in experimental dogs The most likely explanation to this is that the experimental time was too short

Confinement of experimental dogs to cages restricted the physical activities which normally may enhance the pathological processes

CHAPTER V

Comparative Aspects on Legg-Perthes Disease

1 Etiology of Legg Perthes Disease in Man

A Conformity to Sex Hormone Theory

Excessive endosteal bone formation and premature closure of growth plates were found to be the most important features of Legg Perthes disease in the dog These two entities also have been described in man

Waldenstrom (1922) classified the radiographical chanees in Legg Perthes disease In his widely quoted description emphasis was placed on *increased* radiographical density of the femoral head in the initial stage As discussed previously this can result only from more bone than normal

Jonsater (1953) correlated the radiographical and morphological pictures in Legg Perthes disease He noted that in the initial stage the bone was softer than normal in most cases but that the bone was hard upon biopsy puncture in 2 out of 14 cases In the next stage that of radiographically observed fragmentation hard bone was noted in 5 of 14 cases and that in 3 additional cases "the needle encountered alternatively hard and soft parts Jonsater s histological pictures revealed thick trabeculae both in the initial and in the fragmentation stage

Premature closure of the proximal epiphyseal growth plate of the femur has been reported in man (Zemansky 1928 Goff 1954 Edgren 1965) Data from Zemansky s necprosy material are summarized in Table VII

In the monographs by Goff (1954) and by Edgren (1965) the skeletal age of patients with Legg Perthes disease was studied The skeletal age was judged from the occurrence and development of the carpal ossification centres Both studies revealed that *the skeletal age is delayed in Legg Perthes disease*

Longitudinal skeletal growth from epiphyseal growth plates and development of ossification centers are both controlled by the somatotrophin Coexistence of premature closure of growth plates and delay of development of ossification centers may at a superficial glance appear contradictory Instead it most

Table VII Closure of Proximal Epiphyseal Growth Plate of Femur in Legg Perthes Disease in Man (Zemansky 1928)

Age of patient Years	Sex	Proximal epiphyseal growth plate of femur Macroscopical appearance
3	Male	Intact
9	—	Intact
17	Male	Intact
19	Male	Interrupted
10	Male	Interrupted
—	—	Closed
10	—	Closed
13	Female	Closed
16	Male	Closed

Normal time for closure — — the early part of the eighteenth year" (Stevenson 1924)

convincingly supports the theory that these two characteristics of Legg Perthes disease are direct functions of precocious sex hormone activity The sex hormones counteract the somatotrophin with resulting premature closure of growth plates *and* delay of development of ossification centers

B Ischemia of the Femoral Head

Judging from textbooks monographs and shorter communications on Legg Perthes disease in man it appears that avascular necrosis of the femoral head is generally agreed upon as the basic anatomical feature of the disease The cause of this presumed ischemia has never been explained A morphological picture similar to that of spontaneous Legg Perthes disease has not been produced experimentally by interference with the blood supply to the femoral head (Hirayama 1965 Ljunggren 1966)

The distribution of the lesions within the epiphysis and also the metaphysis of the proximal femur in Legg Perthes disease would seem to require the existence of end arteries Otherwise a localized necrosis would be difficult to explain on a circulatory basis There are however no end arteries

Trueta s (1961) explanation that a temporary compression of the lateral epiphyseal vessels would result in localized necrosis must be viewed with skepticism Compression of a major vessel would not explain the haphazard distribution of the lesions Necrosis instead would involve the entire area supplied and would not leave normal marrow and bone tissue intact in an otherwise necrotic area.

It has been suggested that repair of the necroses in Legg Perthes disease is achieved by lateral ingrowth of vessels into the femoral head The present study showed however that fibroplasia and later on osteoblastic apposition is a localized response by the medullary connective tissue around the necrosis This of course would not be possible if the necroses were due to a circulatory disturbance The reparative processes in for instance a renal infarction bear no resemblance to those in medullary and osseous necroses in Legg Perthes disease

As already emphasized the initial change in Legg Perthes disease is increased endosteal bone formation The assumption that a circulatory disturbance would cause excessive formation of bone with increased density is paradoxical Excessive bone formation requires increased anabolic processes This could not result from lowered blood supply The contrary is the self evident requirement

As discussed previously morphological changes are not restricted to the femoral head Excessive endosteal bone formation is universal premature closure of epiphyseal growth plates is also generalized and development of ossification centers is retarded They are part of the picture of Legg Perthes disease and they are *not* coincidental Attempts to correlate these generalized lesions to a localized ischemia of the femoral head *a priori* would be futile

2 Clinical Symptoms and Radiography

The anamnesis and physical examination in Legg Perthes disease usually yield information typical enough to submit the case for radiography and thereby definite diagnosis As emphasized in clinical descriptions of Legg Perthes disease in man determination of the location of pain is not always easy Confusion between hip and knee joint affection may arise Radiography is once again mandatory for differential diagnosis

Concerning the radiographical picture the similarities between the dog and man are obvious

3 Breed and Race Distribution

With regard to constitution four major groups of dogs are recognized viz

1 Acromegalic dogs
2 Normal sized dogs
3 Miniature dogs = proportional dwarfs
4 Chondrodystrophoid dwarfs

Table VIII Constitutional Types Within Same Breed

Acromegalic constitution	Normal constitution	Proportional dwarf constitution Miniature	Toy
Giant Schnauzer	Standard Schnauzer	Miniature Schnauzer	
	Standard Poodle	Miniature Poodle	Toy Poodle
	Airedale Terrier	Irish Terrier	Lakeland Terrier
	Doberman Pinscher	German Pinscher	Miniature Pinscher
	Collie	Shetland Sheepdog	
	Spitz		Pomeranian

The kynological term "toy dog" refers to a small variant of miniature dogs.

Different constitutional types occur within one and the same breed; several examples are given in Table VIII. Such types are recognized as different breeds among kennel people; the classification seems to be artificial.

The analysis of breed distribution in Legg Perthes disease in the dog gave overwhelming proof for the decisive importance of the miniature constitution. There were 7 mongrels in the material used for breed distribution analysis. They all represented cross breeding between miniature breeds, e.g. Pekingese and Pomeranian.

Two breeds classified as chondrodystrophoid occurred in the material, viz. Pekingese and Dachshund, the former significantly over represented and the latter significantly under represented. On the other hand other chondrodystrophoid breeds, such as Boston Terrier and French Bulldog, were absent in the material. It seems logical to conclude that the Pekingese and the Dachshund represent, from a constitutional point of view, a mixture of chondrodystrophoid and proportional dwarfism.

Breeds with normal or acromegalic constitution were completely absent in the material. Further emphasis is furnished by the fact that among over 7 000 German Shepherd dogs, 6 months of age or older, radiographed under the hip dysplasia control program, not one single case of Legg Perthes disease was diagnosed.

The constitutional characteristics of miniature dogs were accounted for in Chapter II. It was shown that the skeletal development is different in miniature breeds compared to normal sized breeds. The functional background for

these morphological manifestations was revealed to be the earlier appearance of sex hormone influence in dogs of predisposed breeds. The question may be posed as to why all predisposed dogs do not manifest the disease. It appears that there is a biological variation within miniature dogs. As shown in Fig. 8, the time of the first heat period and accordingly the degree of morphological changes vary within wide ranges. Only cases which represent the extreme will become clinically manifest and known as cases of Legg-Perthes disease, but every miniature dog is a potential case. The analogy with another disease proven to be constitutional is striking. Chondrodystrophoid breeds are constitutionally predisposed to disc protrusion. All chondrodystrophoid dogs show qualitatively the same age changes in the intervertebral disc but only those with quantitatively advanced changes reach the stage of actual disc protrusion (Hansen, 1952).

Race distribution in Legg-Perthes disease in man was analyzed by Goff (1954). He stated that the disease occurs almost exclusively in white and mongoloid people, although a small number of cases have been reported in Negroes. American Indians are not known to be affected.

4. Age and Sex Distribution

Legg-Perthes disease occurs in both man (Jonsäter, 1953; Goff, 1954; Edgren, 1965, *inter alia*) and dog in juvenile or adolescent individuals. With regard to sex preference of the disease there is, however, a marked difference in the two species. In the dog both sexes are equally affected, but in man there is a male predominance of about 4 to 1 (Jonsäter, 1953; Goff, 1954; Edgren, 1965, *inter alia*).

In a constitutional disease such as Legg-Perthes disease in the dog, equal sex distribution should be expected and it was found. The male preference in man has not been explained.

5. Treatment

Of the two treatments employed in the present material, excision arthroplasty proved so superior that it must be considered the method of choice.

The present study on Legg-Perthes disease in the dog showed precocious sexual maturity to be the etiological factor. Ideally, treatment therefore should aim at correction of the endocrine disorder. Somatotrophin injections would be the logical treatment. For two reasons, however, this treatment can not be advocated in the dog.

Most cases of Legg-Perthes disease are diagnosed at a stage of advanced lesions, at which somatotrophin injections would hardly be expected to have a curative effect.

The miniature constitution is a result of selective breeding of a pathological factor The predisposition for Legg Perthes disease is built in in this constitution By correct treatment of Legg Perthes disease with somatotrophin the whole constitution pathological as it is would also be changed

Nowadays miniature does are high fashioned in many countries Legg Perthes disease is the price for this fashion

6 Nomenclature

The disease under consideration was first described in man by Waldenstrom in 1909 and in the following year independently by Legg Calve and Perthes The disease became known under many combinations of the name of the authors The most common ones are Legg Perthes disease and Legg-Calve Perthes disease The reason for this choice of nomenclature obviously was *that the etiology remained uncovered*

Morphological diagnoses were proposed later but were never universally accepted Such terms include coxa plana osteochondritis osteochondrosis idiopathic osteosis and aseptic or avascular necrosis

The term Legg Perthes disease was used in the present treatise in accordance with previous practice in veterinary medicine and also because of its prevalence in human medicine

Transference of proper name nomenclature from human to veterinary medicine is justified only if reasonably close similarities have been established with regard to symptomatology morphology and at best etiology Absolute congruence can never be required anybody familiar with comparative medicine also appreciates species differences in disease be it constitutional infectious nutritional etc

The similarities of Legg Perthes disease in man and dog are enough to justify common nomenclature One difference is the sex preference Final acceptance of the identity of the human and canine disease requires the etiology described in the dog to be proven valid also in man

Summary

A clinical radiographical morphological and experimental study of Legg Perthes diesase in the dog was presented From the material of 238 spontaneous cases the following conclusions were made

Legg Perthes disease occurred only in miniature breeds i e proportional dwarfs *and thus was proven to be constitutional*

The disease occurred only in adolescent dogs Initial symptoms appeared in dogs from 4 to 11 months of age with an average of 7 months

Female and male dogs were equally affected

Clinical symptoms included lameness with reduction of mobility and sometimes crepitation shortening of the affected leg and muscle atrophy

Left and right sides were equally affected with bilateral involvement in 12 per cent of the cases

The incidence was estimated to be 20 per 1 000 registrations in predisposed breeds

Radiographical examination was required for definite diagnosis Radiographical signs included in chronological order increased density of the femoral head widening of the joint space appearance of areas of decreased density contour irregularities of the femoral head fragmentation and finally osteoarthrosis

Excision arthroplasty gave far better long term results than conservative treatment

The initial morphological change was excessive amounts of endosteal bone due to excessive apposition but not to decreased resorption This change was generalized but accentuated in the femoral head Continuous lateral expansion of trabecular bone resulted in collision of adjacent trabeculae with subsequent osteonecrosis Osteonecrosis apparently also occurred from faulty nutrition of the excessively thickened bone masses Marrow necrosis of unknown pathogenesis were apparent Bone tissue surrounded by extensive marrow necrosis also died Reparative processes included fibrosis osteoclasia and eventually new bone formation

Premature closure of growth plates occurred consistently in Legg Perthes disease

The initial change in Legg Perthes disease i e excessive endosteal bone formation was found to represent an accentuation of a metabolic process typical of the constitution as demonstrated in miniature dogs without Legg Perthes disease Premature closure of the growth plates was likewise found to be a criterion of the miniature constitution

The morphology of Legg Perthes disease and the skeletal morphogenesis of dogs predisposed to the disease were interpreted as evidence for precocious sexual maturity In support of this postulate it was shown that the first heat period occurred earlier in breeds predisposed to Legg Perthes disease than in other breeds

Experiments to reproduce Legg Perthes disease were designed accordingly Juvenile dogs of constitutionally resistant breeds were injected with estrogen or testosterone for various periods of time Resulting lesions identical to those of Legg Perthes disease included premature closure of growth plates excessive endosteal bone formation and necrosis of bone marrow and bone tissue proper As in spontaneous Legg Perthes disease the site of predilection was the head of the femur A more severe generalized skeletal response was ascribed to the large doses used Due to the relatively short duration of the experiments the late sequences of Legg Perthes disease were not encountered

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Stockholm January 1967

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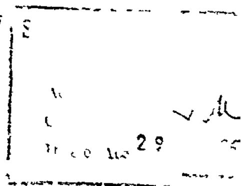
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JOE P MORGAN

SPONDYLOSIS DEFORMANS IN THE DOG

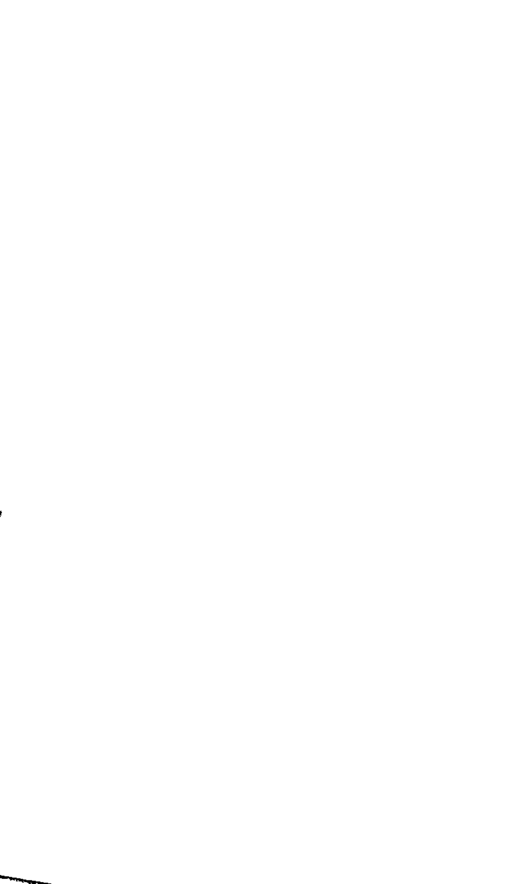
A Morphologic Study with Some Clinical and Experimental Observations



Acta Orthopaedica S
Supplementum No 96
Munksgaard Copenhagen

I ar Hæggstroms Tryckeri AB Stockholm 1967

To My Family



Contents

Introduction and Literature Review

Introduction

Spondylosis deformans in the dog is a condition of the vertebral column familiar to veterinarians It involves the vertebral body at the intervertebral space and is characterized by formation of spurs or complete bony bridges These may be single or multiple in distribution and are often noticeable and impressive The condition is frequently an incidental finding during routine radiographic examination or at necropsy Reports of the etiology pathogenesis frequency distribution and clinical significance have been incomplete and contradictory

The aim of the present investigation is to describe more completely this condition in the dog

There are numerous and more extensive studies of spondylosis deformans in man, but agreement concerning the etiology pathogenesis and clinical significance is lacking The condition has also been described in quadrupeds other than the dog Comparative aspects of the condition are to be considered in a discussion of its structure pathogenesis and clinical significance

Literature Review

Knowledge of anatomical details of the canine vertebral column is essential for an understanding of spondylosis deformans in the dog Anatomical descriptions are readily available (Hansen 1952 King and Smith 1955 King 1956 Smith 1960 1966 Hare 1961 a b Miller *et al* 1964 Hoerlein 1965)

Disagreement on a specific pathogenesis of spondylosis deformans has permitted use of a varied nomenclature The individual bony growth has been referred to as a bony spur spondyle or a vertebral osteophyte The condition has been known as spondylitis deformans traumatica spondylitis ossificans deformans (Pommer 1933) spondylarthritis (Schick 1942) anchylosing spondylitis (Boddie 1949) spondylosis deformans (Hansen 1952) spondylitis deformans spinal osteoarthritis (Glenney 1956) morbus Bechterew (Schnitzlein and Martin 1957) ankylosing spondylitis (Archibald and Cawley 1959) syndesmitis ossificans (Martin 1959) and spondylitis (Hoerlein 1965) It is possible that some of these terms have been used to describe conditions of

traumatic or infectious nature However similarities in morphology have been suggested by the descriptions

Pommer (1933 1936) reviewed earlier studies on the vertebral column of the dog and other animals and described two types of vertebral fusion based on radiographic studies When fusion occurred at the level of the vertebral bodies he used the term spondylitis ossificans deformans or spondylitis deformans traumatica Fusion at the level of the articular processes was referred to as spondylarthritis ankylopoetica Ipolyi (1939 1941) continued to use Pommer s classification and terminology in a report on examination of 229 dogs Pommer s classification was again used in its original form by Hoerlein (1965)

The incidence of spondylosis deformans in the dog has been related to sex age and breed The condition has been described in all ages with higher incidence in old age (Pommer 1933 Ipolyi 1939 1941 Schick 1942 Debard 1949 Hansen 1952 Fankhauser 1955 Glenney 1956 Martin 1959 Schnitzlein 1960 Morgan *et al* 1966 Read 1966) Both number of affected dogs and degree of involvement have been shown to increase with age (Schick 1942 Morgan *et al* 1966)

Most reports have indicated equal occurrence of spondylosis deformans in both sexes (Pommer 1933 Ipolyi 1939 Hansen 1952 Martin 1959 Read 1966) However a higher incidence in both male (Bruder 1955 Fankhauser 1955) and female (Morgan *et al* 1966) has been reported

It has been proposed that there is a predisposition in the boxer (Hansen 1952 Glenney 1956 Martin 1959 Schnitzlein 1960 Zimmer and Stahli 1960 Morgan *et al* 1966) and in the larger breeds (Pommer 1933 1936 Ipolyi 1939 1941 Boddie 1949 Debard 1949 Fankhauser 1955 Martin 1959 Morgan *et al* 1966) The dachshund has been reported to have a lower incidence (Pommer 1933 1936 Fankhauser 1955 Morgan *et al* 1966) although others have suggested a higher incidence (Archibald and Cawley 1959)

Distribution patterns showing a higher involvement in specific areas throughout the vertebral column have been described (Pommer 1933 Hansen 1952 Bruder 1955 Glenney 1956 Martin 1959 Schnitzlein 1960 Morgan *et al* 1966 Read 1966)

Total incidence reported has ranged from 9 to 75 per cent (Pommer 1933 Ipolyi 1939 1941 Hansen 1952 Glenney 1956 Schnitzlein 1960 Morgan *et al* 1966 Read 1966)

Varying suggestions of etiology and pathogenesis of spondylosis have been offered Pommer (1933) reported that stresses on the ligaments and periosteum were significant These stresses could be normally present in active dogs or could be due to degenerative discs trauma or repeated pregnancies

Ipolyi (1939 1941) thought that intervertebral disc softening due to trauma muscle or ligamentous weakening must always precede vertebral changes esulting motion and disc herniation exerting pressure on the periosteum were portant However he discounted the importance of the longitudinal ligament the pathogenesis

Schick (1942) Fankhauser (1948) and Hansen (1952) also associated disc anges with spondylosis deformans Schick noted in a radiographic study that fected vertebral bodies were sclerotic and disc spaces narrowed Hansen scribed two types of disc protrusion in the dog Type I protrusions were used by a total rupture of the anulus fibrosus and were massive in scope ype II protrusions were more limited and were caused by a partial rupture of e anulus fibrosus with a bulging of the dorsal surface of the disc He con uded that spondylosis deformans and the two types of disc protrusions were parate morphologic expressions of disc degeneration Degeneration resulting protrusions of type II had similarities to that associated with spondylosis eformans Simultaneous presence of spondylosis deformans and type II otrusions in the cervical region of the dog was found rarely by Olsson and ansen (1952) Hansen (1952) also thought that the attachments of the entral longitudinal ligament might have played a role in the development of steophytes if changes in the disc were minimal

Martin (1958 1959) observed that intervertebral discs associated with ertebral osteophytes were normal in appearance If there were changes in e discs he interpreted them as appearing later than the osteophytes He emed to be influenced by descriptions of ankylosing spondylitis in man and iggested an association of changes in the dog with prostatic disease and icro iliac change He introduced the name syndesmitis ossificans into eterinary literature recognizing a primary ossification of vertebral ligaments

Schnitzlein and Martin (1957) and Schnitzlein (1960) also stressed the role f the ligaments and described the vertebral changes as morbus Bechterew his is synonymous with spondylarthritis ankylopoetica or ankylosing spondy tis

Archibald and Cawley (1959) considered that the condition satisfied the efinition of a rheumatoid spondylitis and referred to it as ankylosing pondylitis

Throughout the review of literature the alternate use of the terms spondy*litis* nd spondy*losis* was obvious Hansen (1952) appeared to be the first in eterinary literature to use the term spondylosis Hoerlein (1956 1959) returned o the use of spondylitis since he described the condition as inflammatory with omplete ossification of vertebral ligaments In 1965 he considered spondy osis deformans to be similar to specific osteomyelites of vertebrae such as hose due to mycotic infection and spirocerca lupi Glenney (1956) also lefined the condition as an inflammation of the vertebra

Clinical significance has been attributed to spondylosis deformans from the time of early works Pommer (1933 1936) described cases both with and without clinical signs However it would be difficult to determine the exact part disc herniation played in his material In his study of calcinosis and enchondrosis intervertebralis (1937) he stated that the clinical appearance due to disc herniation was very similar to that caused by spondylitis ossificans

Ipolyi (1939 1941) described clinical signs in dogs progressing to paralysis but mentioned that 50 per cent of his cases with spondylosis deformans were asymptomatic He found no relationship between degree of spur formation and symptoms

Differential diagnosis of paraplegia or paresis in the dog has frequently included spondylosis deformans (Fankhauser 1948 1955 Boddie 1949 Debard 1949 Hoerlein 1953 1956 Muller 1955 Glenney 1956)

Debard (1949) described pain as a result of vertebral spurs causing tension on vertebral ligaments He also reported pain due to pressure on spinal nerve roots

Hoerlein (1956) briefly described vertebral osteophytes in a discussion of clinical conditions affecting the vertebral column of the dog Later (1965) he attributed pain to resulting pressure on spinal nerves or spinal cord Belkin (1958) also described involvement of the spinal cord or nerves as causing clinical symptoms

Vertebral osteophytes have been described in dogs in which there were no clinical signs pointing to the vertebral column (Brook 1936 Martin 1958 1959 Morgan *et al* 1966)

Morphologic Studies

A Material and General Methods

The present morphologic study included a material of 100 vertebral columns with spondylosis deformans This material was obtained from two different groups of dogs

The majority of cases was included in a group of 119 vertebral columns randomly selected from the Pathology Department of the Royal Veterinary College Stockholm Sweden They were removed from necropsied dogs 2 years of age and older from October 1964 until May 1965 This material was used in studying the incidence of spondylosis deformans and allowed statistical evaluation of findings

The second group consisted of 26 vertebral columns specifically selected because they were affected with spondylosis deformans These dogs were either presented to the College for euthanasia or submitted for necropsy

Information concerning age sex and breed was obtained in all cases except two Necropsy reports were available for study on all dogs obtained from the Pathology Department

The routine method of examination for the entire material was to disarticulate vertebral columns at the atlanto-occipital and sacro iliac articulations If these last mentioned joints were fused the pelvis was removed from the cadaver together with the vertebral column

With a band saw ribs were cut 2 to 5 centimeters from the vertebral column The large muscle masses were removed and an identification tag attached

The entire specimen was then radiographed Depending on the dogs size a total of six to ten exposures was made in two projections on non screen film

The first part of the gross examination was directed toward soft tissue structures adjacent to the vertebral column

Size and location of osteophytes on the vertebral margins were noted at gross dissection and compared with the radiographic appearance Size was then recorded using a technique similar to the one described by Nathan (1962) (Fig 1) Five stages of development were defined Stage one represented earliest gross findings which were palpable nodules not identified on the macro radiographs The changes were located over intervertebral spaces and adjacent

Stage two was characterized by further maturation of the disc with most of the gross changes present in the nucleus pulposus It was more fibroid and dull in appearance becoming grayish or milky white in color A distinction between anulus and nucleus was still present The anulus had become more coarse in appearance and minimal separation between lamellae could be seen

Stage three included all forms of nuclear calcification and applied with few exceptions to chondrodystrophoid breeds Various degrees of intradiscal nuclear protrusion and true nuclear prolapse were noted Generally the appearance of the anulus fibrosus was similar to that found in stage two

Stage four included discs with marked degeneration without calcification The nucleus appeared firm in consistency fibrous and sometimes lumpy It could not easily be distinguished from the inner anular fibers Large cavities or stellate shaped fissures were present in the nucleus There was further development of the coarseness in the anulus fibrosus Yellowish discoloration was rather common in this stage and dehydration was obvious

Stage five included discs severely degenerated with little recognizable tissue remaining Because degeneration was extensive it is possible that calcified material was overlooked The tissue fragmented badly on cutting due to excessive dehydration There were large cavities and fissures throughout the disc Intradiscal nuclear protrusion and anular bulging was noted Discoloration was common and varied from dark grey or brown to bright red

The gross morphologic condition of vertebral synovial joints and costo vertebral articulations was recorded Those joints which had smooth and glistening cartilage with no discoloration or marginal osteophytes were con sidered normal Joints with erosion pitting or discoloration of the cartilage and or marginal osteophytes were classified as changed

A group of 49 vertebral columns was handled in such a way that thorough dissection was not possible This group included 9 that were boiled to remove soft tissue 6 that were used for isotope studies to be reported in a later paper 6 that were cut sagittally for examination and photography 20 that had sections removed for microscopic or radiographic studies in such a way that complete dissection was not possible 3 that were excluded because of radio-graphic signs of metastatic neoplasia in the vertebrae and 5 that did not show any changes of spondylosis deformans

Throughout the present study each intervertebral space was identified by the number of its intervertebral disc counted from the cranial to the caudal region (Hansen 1951 1952)

Chi square (with Yates correction) or t tests were used for statistical evalua tion Means are given together with the standard deviations The results of

statistical analysis were recorded as not significant ($P>0\ 05$) almost significant ($0\ 05>P>0\ 01$) significant ($0\ 01>P>0\ 001$) and highly significant ($0\ 001>P$)

Certain methods were used that were specific for a particular type of investigative procedure These will be described later

B Results

1 Incidence and Distribution

The occurrence of vertebral osteophytes was examined from different aspects The incidence irrespective of number of osteophytes per vertebral column within the randomly selected material was considered from the standpoint of sex age breed and weight of the dog The material was also divided into groups of dogs of chondrodystrophoid and non-chondrodystrophoid breeds and the incidence determined Distribution throughout the vertebral column location on the vertebral margin and the average size and number of osteophytes on each affected vertebral column were determined The incidence was more thoroughly studied in the three most highly represented breeds from the randomly selected material

Incidence and Causes of Incidence Variation

The incidence of spondylosis deformans in the total material was 71/116 (0 61)

Sex — The frequency of affected males was 34/53 (0 64) and of affected females was 37/63 (0 59) This difference in sex distribution was not significant ($\chi^2 = 0\ 16$ d f $= 1$)

Age — Dogs were divided into age groups and evaluated for incidence of vertebral osteophytes (Fig 3) Approximately 50 per cent were affected by the age of 3 to 6 years By the age of 9 years 75 per cent had changes and the figure approached 100 per cent in dogs of still higher age The effect of age could also be noted when the incidence of each of the five stages of osteophytes was plotted following division of the entire material into three age groups (Fig 4)

Breed — The incidence of vertebral osteophytes could only be compared in the three breeds with greatest representation Frequency in the German shepherds was 9/13 (0 69) dachshunds 18/24 (0 75) and boxers 18/19 (0 95) Heterogeneity between breeds was measured and the difference in frequency was determined to be not significant ($\chi^2 = 1\ 84$ d f $= 2$)

Constitution — Hansen s definition of chondrodystrophoid breeds (1952) was used as a criterion for division of the material The frequency of spondylosis deformans in chondrodystrophoid breeds was 22/29 (0 76) and in non chondrodystrophoid breeds was 49/87 (0 56) Heterogeneity between groups

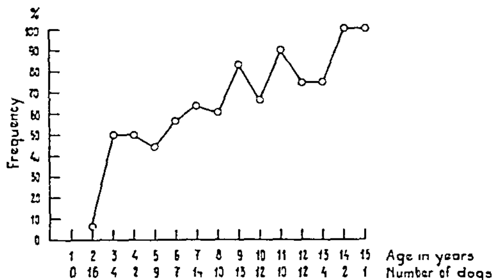


Fig 3 Frequency distribution of spondylosis deformans as related to age in the randomly selected material

was measured and the difference was determined to be not significant ($\chi^2 = 3.57$ d f = 1)

Weight — Comparison was also made following division of the randomly selected material into weight classes Frequency in dogs weighing 10 kg or less was 18/38 (0 47) 10 1 to 20 kg was 15/27 (0.56) 20 1 to 30 kg was 23/34 (0 68) and over 30 kg was 15 17 (0 88) Heterogeneity between the different weight classes was measured and determined to be almost significant ($\chi^2 = 7.21$ d f = 3)

Number of Osteophytes on Each Vertebral Column

The number of osteophytes present on each vertebral column from dogs in the randomly selected group was determined The mean frequency in those under 4 years was 3.50 (± 3 12) 4 to 10 years was 10 66 (± 8 26) and over 10 years was 12 30 (± 8 87) The difference in number of osteophytes between those under 4 years and those 4 to 10 years was highly significant (t = 3.58 d f = 46) the difference between those 4 to 10 years and over 10 years was without significance (t = 0 74 d f = 65) and the difference between those under 4 years and over 10 years of age was significant (t = 3 64 d f = 25)

In the total affected material the mean frequency of number of osteophytes on each vertebral column of dogs under 4 years was 7 00 (± 4 34) from 4 to 10 years was 10 96 (± 8 81) and over 10 years was 12 49 (± 8 84) The differences between those under 4 years and those 4 to 10 years, and between those 4 to 10 years and over 10 years were without significance (t = 1 84 d f = 57 t = 0 83 d f = 92) The difference between those under 4 years and over 10 years was almost significant (t = 2 44 d f = 45)

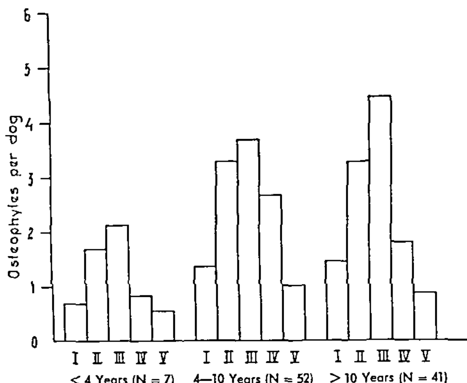


Fig 4 Frequency of the five stages of vertebral osteophytes in 100 dogs with spondylosis deformans following division into three age groups

The number of osteophytes present on each affected vertebral column was specifically determined for each of the dogs belonging to the three most highly represented breeds The average numbers were 5 94 (± 5 98) in the dachshund 11 11 (± 8 99) in the German shepherd and 17 61 (± 8 72) in the boxer Pairwise comparisons were made and the difference between the number of osteophytes found in the dachshunds and boxers was highly significant (t = 4 67 d f = 34) The differences found between the dachshunds and German shepherds and between the German shepherds and boxers were not significant (t = 1 50 d f = 25 t = 1 79 d f = 25)

Incidence of Stages of Osteophytes

The average incidence of each of the five stages of osteophytes per affected vertebral column was determined following division of the entire affected material into three age groups (Fig 4)

The average incidence of each of the five stages of osteophytes found on the affected vertebral columns of dogs from the three most highly represented breeds was determined (Fig 5)

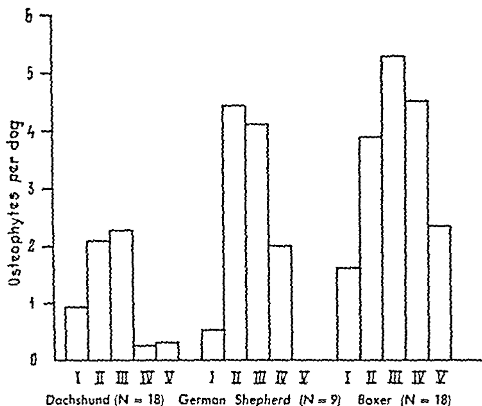


Fig 5 Frequency of the five stages of vertebral osteophytes in affected vertebral columns in the three breeds most highly represented

Distribution of Osteophytes within the Vertebral Column

Distribution was plotted graphically (Fig 6) Frequency in the cervical region was low compared to the remainder of the vertebral column No osteophytes were found involving the first cervical vertebra or the odontoid process of the second A low frequency was also noted in the first three thoracic segments and was followed by a steady increase with a peak at disc number 15 There followed a decline in number of osteophytes from disc number 16 through 25 and a second peak was present at disc 26

Distribution of each of the five stages of osteophytes was recorded graphically (Fig 6) Most in the cervical region were small with only two belonging to stage five The majority of spurs in the thoracic region was of stages two and three while those of stage five were relatively rare Most of the osteophytes in the lumbar region were of stages three and four and the number of stage five spurs was greater than in other areas of the vertebral column

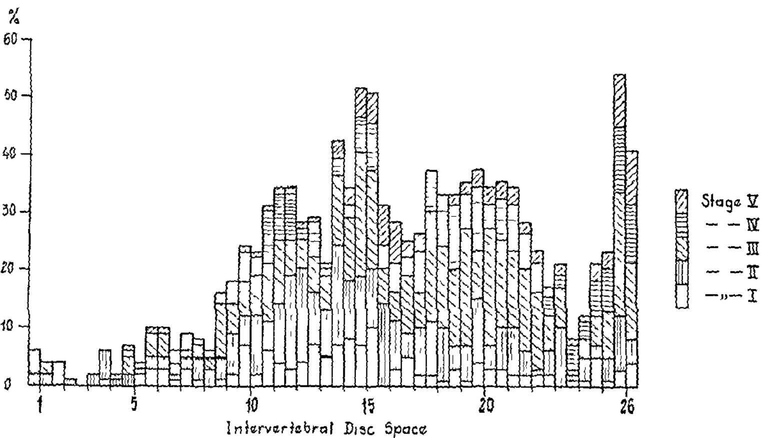


Fig 6 Frequency distribution of each of the five stages of spondylosis deformans in 100 affected dogs as it is related to both cranial and caudal aspects of each intervertebral disc space

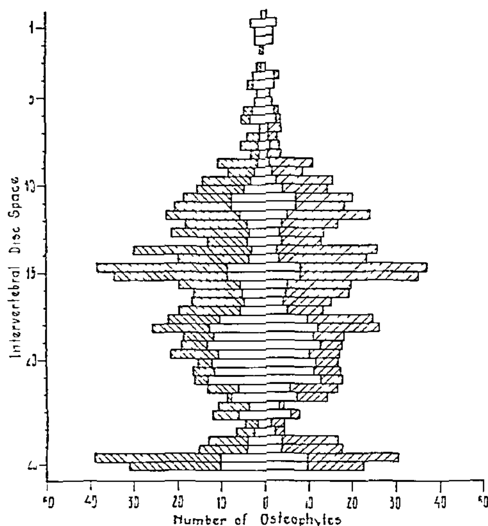


Fig. 7 Distribution of osteophytes in 100 dogs with spondylosis deformans as related to position on the vertebral margin of both cranial and caudal aspects of each inter vertebral space

Distribution of Osteophytes on the Vertebral Margin

The exact location of each osteophyte was recorded according to a previously described method (page 12 Fig 7) The majority of spurs in the cervical region was located on the ventral midline Usually they represented a continua tion of the prominent ventral ridge as found especially on C 2 3 4 No osteophytes were found located dorsally or near the intervertebral foramina

The pattern changed from disc spaces 7 through 17 with approximately two thirds of the spurs equally divided to the right and left of the midline From spaces 18 through 23 the majority of osteophytes was again located on the midline A shift was noted from disc space 24 caudally to the lumbo-sacral junction Here the spurs were located to the side of the midline but in a lower percentage than in the mid thoracic region

Dorso-lateral new bone growth was noted around intervertebral foramina and plotted as lateral in position (Figs 8 10 14) In the thoracic region osteophytes originated from the dorsal portion of the costal fovea and from the costal fovea of the transverse process of the vertebrae (Fig 10) Two dorsal osteophytes near the midline were located by gross examination These were in different vertebral columns on the cranial aspect of disc spaces number 8 and 16 Both were small and there was no gross evidence of spinal cord pressure They were not plotted (Fig 7)

Spurs were frequently located around coccygeal discs but location and number were not recorded No osteophytes were noted on the ventral aspect of the midportion of the sacrum

2 *Macroscopic and Macroradiographic Studies*

New bone growth was found in numerous locations along the junction of the vertebral end plate and vertebral cortex (Fig 8) and was found both alone or matched with equal or unequal development on the opposing vertebral body (Figs 10 11 12 13 14 15) The bony growths ranged in size from small barely discernible nodules to massive ankylosing bridges (Figs 13 14 15) They were single multiple in scattered locations or concentrated in one area of the vertebral column Typically the new growth extended around the intervertebral disc (Figs 10 11 12 13 14 15) Often the spurs were located dorso-laterally and involved the costo-vertebral articulations (Figs 10 14)

The extent of development of many spurs could not be accurately deter mined from the cadaver because of tissue between two opposing osteophytes Macroradiographs or boiled specimens were required to determine the extent of ossification

Ventral and Lateral Osteophytes

The general appearance of an osteophyte was that of a scoop with the tip extending toward the disc It usually presented a sloping and smooth ventral or lateral surface that blended gently with the cortex of the vertebral body (Figs 9 10 11 12 13 14 15) This was best seen in osteophytes in stage three or larger Actual ankylosis was rare and an interlocking of small finger like projections was more common (Fig 11) The width of the osteophyte had no relation to the extent of longitudinal development





Fig 8 Caudal surface of L6 of a boiled specimen from a German shepherd (12 yr ♀) Extensive bony growth occupies most of the periphery of the vertebral end plate The osteophytes do not meet at the midline ventrally where the longitudinal ligament was located The dorso-lateral spurs are within the intervertebral foramina but taper sharply as they enter the spinal canal

Fig 9 Lateral view of the caudal end of L5 following sagittal sectioning of the vertebral column of a boxer (8 yr ♀) The osteophyte is of stage four and located laterally and ventrally



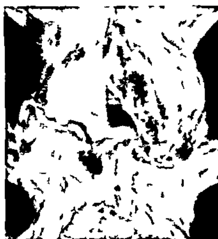


Fig 10 Lateral view of the right side of boiled thoracic vertebrae T9—10 from a German shepherd (12 yr ♀) The costo-vertebral joint covers the intervertebral space and the ventral osteophytes blend with the periarticular osteophytes There is encroachment upon the intervertebral foramen The osteophyte on the right is in stage four and that on the left is in stage three

Fig 11 A ventral view of a boiled specimen of L6—7 from a German shepherd (12 yr ♀) The interlocking osteophytes bridge the intervertebral space without fusion The absence of osteophytes on the ventral midline is at the location of the ventral longitudinal ligament Longitudinal grooves are seen laterally on the osteophytes Numerous foramina penetrate the surface of the new bone growth as well as the vertebrae



Fig 12 The right side of T12—L2 after sagittal sectioning of the vertebral column from a boxer (9 yr ♀) The osteophytes are of stage four There is a free segment of bone between L1 and L2 that is not in contact with adjacent vertebrae Disc spaces are of normal width Disc 19 (in the center of the picture) is discolored and has an intradiscal fissure

Separate centers of ossification were frequently noted on the macroradiographs of the ventral portion of the anulus fibrosus (Fig 16) These centers were usually in conjunction with marginal spurs but in some cases were the only radiographic sign of osteophyte formation at the intervertebral space These crescent shaped bodies did not have the appearance of fracture fragments No fracture line was identified and the bodies were widely separated from the vertebrae The shape of these free segments was not similar to that usually taken by protruded disc material

Frequently osteophytes became so large that spurs from cranial and caudal corners of a vertebral body met at the midpoint of the ventral margin (Figs 12 14 15) A great increase in dorso-ventral diameter of the vertebral body resulted

Dorsal and Dorso-lateral Osteophytes

Only two dorsal osteophytes were found Dorso-laterally located osteophytes were more common and represented a continuation of large lateral spurs (Fig 8) In the thoracic area osteophytes occurred associated with costo-vertebral articulations (Fig 10) In this location they usually permitted a free pathway for spinal nerve roots



Fig 13 Radiograph of T4—7 following removal from the cadaver of a standard poodle (10 yr ♂) The osteophytes are of stage two (arrows) Disc spaces are of normal width

Fig 14 Radiograph of T8—11 following removal from the cadaver of a bull mastiff (7 yr ♀) Starting from the right the osteophytes are of stages three four and five A dorso-lateral osteophyte on the caudal aspect of T9 (arrow) projects into the intervertebral foramen Disc spaces are normal in width



Fig 15 Radiograph of L3—5 following removal from the cadaver of a German shepherd (6 yr ♀) The osteophytes are of stage five There is narrowing of the intervertebral foram n at disc 23 due to dorsal extension of the dorso lateral osteophyte and new growth from the accessory process (arrows)

Fig 16 Radiographs of T3—7 following removal from the cadaver of a boxer (9 yr ♀) The osteophytes are of stage four and are characterized by the flat or crescent shape of the isolated piece of bone ventral to the disc Width of the disc spaces is normal Presence of the rib heads makes diagnosis of change in the region of the dorsal portion of the discs and the intervertebral foramina difficult

Atypical Osteophytes

Cases were noted in which osteophytes differed from those described above These formed at intervertebral spaces that were narrow and there was an increase in the amount of bone in the vertebral end plates These osteophytes were more dense and appeared as straight ventral projections from the vertebra instead of a scoop of tooth shaped spur (Fig 17)



Fig 17 Radiograph of T12—L2 following removal from the cadaver of a great Dane (2 yr ♀) Disc spaces 19 and 20 are narrowed and the stage three osteophytes (arrows) are atypical in shape and direction of growth

Ventral Longitudinal Ligament

Macroscopic examination of the ventral longitudinal ligament revealed the following In cadavers and boiled specimens it was common to find a notch in an osteophyte or between two osteophytes in which the longitudinal ligament lay (Figs 8 11) This notch remained even though the bony growth became large and often osteophytes encased the ligament (Fig 19) In the cervical region new bony growth was usually on the midline and the ventral longitudinal ligament was elevated in a ventral direction by the osteophyte

Other longitudinal grooves of smaller size were seen in boiled specimens (Fig 11) These grooves apparently were due to pressure from overlying soft tissue structures Nerves from the last two lumbar segments frequently lay in smooth and well-outlined tracks especially at the lumbo-sacral junction No compression of spinal nerves was noted grossly Numerous foramina of different sizes were identified on the surface of the osteophyte (Fig 11)

Vertebral End Plates

Vertebral end plates appeared normal on boiled specimens and were separated from osteophytes by a circumferential groove ventrally and laterally (Figs 8 9) In no case was an osteophyte found extending from the central portion of a vertebral end plate Any bony bridge that formed at the intervertebral disc space was at the periphery of the end plate and followed the outer ventral or lateral contour of the disc There was seldom any macroradiographic evidence of increased deposition of bone adjacent to the end plate

The majority of osteophytes developed around intervertebral spaces that were of normal width (Figs 12 13 14 15 16) Excluding chondrodystrophoid breeds there were only a few instances of associated calcification of intervertebral discs

3 Microscopic Studies

Three techniques were used for the description of microscopic morphology of vertebral osteophytes viz microradiography tetracycline labelling and conventional histology

a Microradiographic Studies

Following gross examination sections were cut for processing as undecalcified specimens Sagittal sections were taken at or near the median plane and included both vertebrae and intervening disc They were taken from 61 dogs at most interspaces of the vertebral column to include regions representative of the five stages of growth of vertebral osteophytes and normal vertebral bodies A small number of sections in other planes was also made The bone was fixed and dehydrated in successive baths of absolute alcohol and was then imbedded in a monomer of methyl methacrylate When this had hardened it provided support for the section during cutting grinding and polishing The procedure used was a combination and modification of earlier techniques It has been described by Olsson and Rietz (1966)

The 100 μ section of undecalcified bone was then microradiographed The photographic plate was processed and the resulting microradiograph was viewed through a microscope For basic information about microradiography the reader is referred to the review by Eriksson (1965)

Normal Mature Vertebrae

The description of the microradiographic appearance of mature vertebrae was primarily based on sagittal sections The vertebral end plate was made of compact bone but appeared to be different from the compact bone forming the cortex of the vertebral body The end plate was repeatedly crossed by vascular channels from the marrow containing portion of the vertebral body to the surface of the end plate In addition there were numerous small cavities on the surface that created a 'pitted appearance Both of these findings were more obvious in the center of the plate adjacent to the location of the nucleus pulposus The peripheral portion of the end plate was thicker ventrally while the center was noticeably thinner (Fig 18)

On sagittal sections the concave surfaces of both cranial and caudal vertebral end plates were identified and were more pronounced if the sections were taken near the median plane The concavity occupied approximately one third of the dorso ventral diameter and was slightly dorsal in location It corresponded to the position of the nucleus pulposus (Fig 18)

The end plate turned away from the intervertebral space at the ventral border of the vertebral body However more of a sharp 'corner was formed

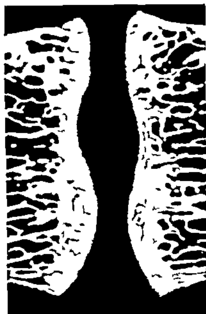


Fig 18 Microradiograph of a sagittal section of L6—7 from a boxer (8 yr ♂) Thickness and contour of the vertebral end plate and width of the interspace are normal (× 4)

where the end plate met the cortex dorsally There was still a smooth transition between end plate and vertebral cortex both dorsally and ventrally (Fig 18)

The trabecular pattern of the vertebral body was oriented in a longitudinal direction with interweaving of the trabeculae (Figs 18 20) On transverse sections the trabecular pattern through the body was found to be in the form of tubes with appearance of a honeycomb (Fig 19)

Different stages in growth and maturity of Haversian systems were seen in both transverse and sagittal sections Most osteons were aligned in a cranio caudal direction and thus better seen on transverse sections

Forming Osteophytes

The first evidence of development of osteophytes appeared to be at or near the ventral margin of the vertebral end plate Earliest changes consisted of a small mound with a calcified cartilage surface Some small osteophytes had a core of rather mature appearing bone trabeculae These corresponded to a stage two osteophyte (Figs 20 21)

Regardless of the stage of the developing osteophyte the same pattern was seen on the surface A deposition of mineral within the matrix around the chondrocytes was noted within and just outside the zone of calcifying cartilage

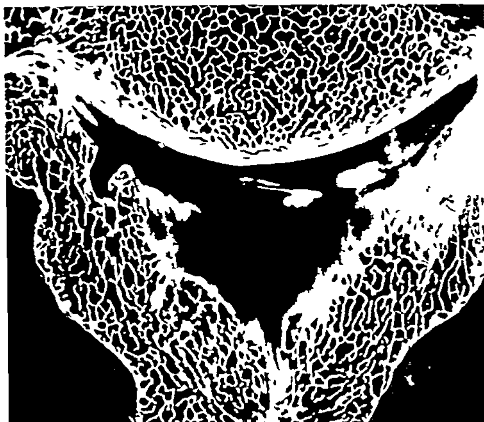


Fig 19 Microradiograph of a transverse section of an osteophyte and the ventral portion of L3 taken from a German shepherd (6 yr ♀) The vertebral body has a normal trabecular pattern with many tubules extending cranio-caudally A tendency to form the same tubular pattern is noted in the osteophyte The form of the osteo phyte suggests early formation laterally and subsequent joining on the ventral midline (× 7)

(Fig 22) The zone of calcified cartilage contained cavities with an irregular border These were adjacent to smaller cavities with a smoother border A varying amount of bone was seen around the smaller cavities creating osteon like structures (Fig 23) With an increase in amount of bone the size of the cavities decreased Small foci of calcified cartilage were identified between the bony islands (Fig 23)

With formation of stages three and four the osteophytes lengthened the area of their attachment with the vertebral cortex in a direction away from the disc (Fig 20) Calcified cartilage was only found on the surface of the osteophyte directed toward the disc and on the ventral portion of the distal tip The calcified cartilage was equally distributed or was concentrated more at the tip of the spur (Fig 20)

Fig. 20 Microradiograph of sagittal section of T9—10 from a German shepherd (6 yr ♀) The osteophyte on the left is of stage two Dorsal to the osteophyte is an indentation with irregular contour and sharp margins Outside this notch are small dense fragments The osteophyte on the other vertebra is of stage three It has a wide base of attachment and the interposed ventral vertebral cortex has been almost removed Trabeculae of the osteophyte blend with the trabeculae of the vertebra The groove is evident and small dense fragments are seen adjacent to this area The ventral cortex of the osteophyte consists of compressed lamellar bone (× 6)

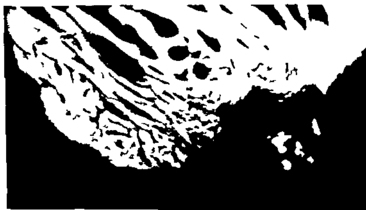


Fig 21 Detail of the osteophyte on the left in fig 20 The appearance of the indentation and fragmentation is suggestive of an avulsion This is the site of attachment of the outer anular lamellae The outer part of the osteophyte consists of calcified cartilage (× 30)

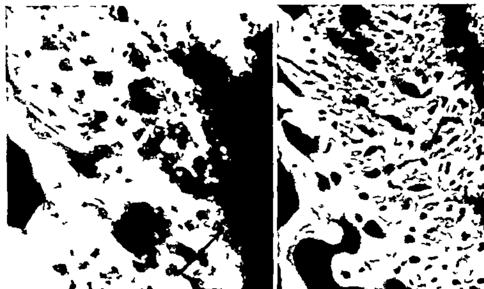


Fig 22 Microradiograph of the surface of an osteophyte located on L3 of a German shepherd (6 yr ♀) The wide zone of calcified cartilage is adjacent to mature bone on top and to the left of the picture Chondrocytes (arrow) are seen in stages of calcification of their matrix (× 150)

Fig 23 Microradiograph showing the surface of an osteophyte located on L5 of a German shepherd (6 yr ♀) The surface of calcified cartilage has interspersed bony trabeculae and small osteon like appearing bone formations Mature bone is at the lower left corner of the picture At the top center of the picture is a large cavity with an irregular border of calcified cartilage (× 75)

As the osteophytes increased in size mature appearing trabeculae were noted within the osteophyte The trabeculae were thicker and the number of develop ing Haversian systems was greater than noted in the host vertebrae The ventral and or lateral cortex of the osteophyte had the appearance of compressed lamellar bone with frequent formation of Haversian systems (Fig 20)

The previously described circumferential groove at the periphery of the vertebral end plate was noted in all but the earliest stages of development of osteophytes (Fig. 20) At the bottom of the groove was a notch within the vertebral end plate Usually the notch was filled with calcified cartilage This cartilage appeared more dense radiographically than the calcified cartilage on the surface of the osteophyte (Fig 24 25) In some cases the notch appeared empty and there were small dense fragments adjacent to it Bone islands were not common within the cartilage in the notch The groove narrowed as the spur developed into stages three four and five However it still retained a discernible amount of calcified cartilage There was little relation between the appearance of the groove and the notch and the stage of the osteophyte

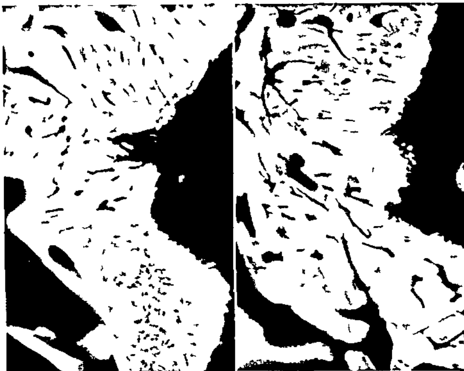


Fig 24 Microradiograph of the notch of a stage four osteophyte located on the caudal aspect of T11 The defect in the vertebral end plate is probably due to an avulsion of the bone and loss of the calcified debris during preparation of the specimen Tiny fragments of dense tissue are adjacent to the empty notch The cartilage bordering the defect is dense and has a different appearance to that on the surface of the osteophyte The disc space is to the right of the picture (× 50)

Fig 25 Microradiograph of the notch of a stage four osteophyte located at disc 7 of a German shepherd (6 yr ♀) The notch contains packed calcified debris with free small fragments of dense tissue near the surface The disc space is to the right of the picture (× 50)

Calcified cartilage was not evident on the ventral and/or lateral cortical surface of the osteophyte in any stage of development (Fig 20) There was no line of demarcation between the cortex of the osteophyte and the vertebral body (Fig 20)

The vertebral cortex at the area of origin of the osteophyte became less distinct with growth of the osteophyte to stages three four and five (Fig 20) In some sections the cortex could not be identified and the trabeculae of the vertebrae and osteophyte were interwoven Even with disappearance of the interposed cortex the previously described groove often remained

Dorsal osteophytes were found more commonly on the microradiographs



Fig 26 Microradiograph of a sagittal section of the ventral corner of the cranial end of T5 from a standard poodle (10 yr ♂) The osteophyte is of stage two The groove is filled with calcified cartilage and the entire contour of the osteophyte is smooth The surface of the osteophyte toward the disc and the tip are covered with calcified cartilage (×40)

than on gross dissection They were composed of both calcified cartilage and more mature appearing bone and were formed on the corner of the vertebral end plate and dorsal cortex In these cases there was no formation of a circum ferential groove

Union of two spurs was indicated by the presence of a wide band of calcified cartilage joining the two surfaces Small bony islands were identified within the calcified cartilage The same pattern of change was seen as on the surface of the growing osteophyte except that the calcified cartilage covered a wider space and appeared to have less organization

Mature Osteophytes

Many spurs appeared to have ceased active growth This was determined by formation of mature appearing trabecular bone with a cortical bone completely covering the osteophyte In other spurs the calcified cartilage surface was still present but neither additional calcification within the matrix nor formation of bony islands was seen In either case the groove was smaller and appeared to be in the stage of closure (Fig 26) This apparent cessation of activity of

growth of the osteophyte occurred at stages two three or four Osteophytes in stage five had achieved complete bridging ventrally and/or laterally to the intervertebral space

Cases were seen frequently in which new bone growth extended the entire length of the vertebral body between osteophytes on both cranial and caudal borders This was usually associated with osteophytes in stages four or five but often occurred with stage three In these cases the old ventral cortex of the vertebral body was gone and the ventral cortex of the osteophyte became the new vertebral cortex The width of the cortex and trabeculae of the osteophyte was the same as in the vertebra

Growth of osteophytes as determined by the presence of incompletely calcified cartilaginous surfaces appeared to be an individual characteristic This was not a consistent finding on osteophytes throughout one vertebral column However there seemed to be a tendency for growth to be more nearly equal on both sides of the same intervertebral space

Free Bony Segments

Microradiographs often demonstrated calcified cartilage and/or bony segments lying free in the ventral anular area Changes of this type were classified within stage four Macroradiographs and gross dissection showed the segments to have no attachment to adjacent vertebral bodies

The segments were generally composed of calcified cartilage with bony islands but as they enlarged they developed a trabecular pattern similar to that found in the vertebral body In some cases cartilage on the entire circumference of the free segment and advancing tips of adjacent osteophytes had different degrees of calcification The growth pattern of these free segments was identical to that seen on the surfaces of osteophytes attached to vertebrae (Fig 27) Joining of a free segment to a vertebral spur or to another free segment was characterized by a wide connecting band of calcified [illegible] with the earlier described characteristics

In other discs part or all of the free segment was composed of [illegible] lamellar bone and little sign of activity was noted

Changes Associated with Osteophytes

Amorphous mineral debris was present in the ventral ar[illegible] with and without associated osteophyte formation In some [illegible] close to and in others unassociated with active or inactive [illegible] cases debris was noted in various stages of incorpora[illegible] segments or attached osteophytes (Fig 27)

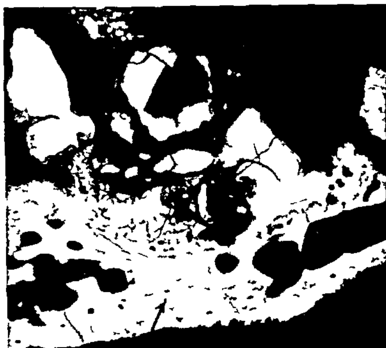


Fig 27 Microradiograph of a free bony segment within the ventral portion of disc 17 of a German shepherd (6 yr ♀) Large amorphous dense masses lie within the soft tissue and are being incorporated into the segment The majority of the free segment is composed of calcified cartilage with small bone islands around small cavities (arrow) Other larger cavities are also lined with bone tissue (×40) (This is the same disc space as seen in fig 22)

Width of disc spaces and density of vertebral end plates were usually normal (Fig 20) However several sections had marked narrowing of disc spaces and increased width of vertebral end plates In these the surface of the end plate had lost its 'pitted appearance and appeared worn (Fig 28) The pattern of osteophytes in these cases was similar but lacked the seemingly purposeful manner of development characterizing those described earlier Origin of the spurs took place at a greater distance from the corner of the vertebral body Direction of growth was more frequently ventral or away from the vertebral body and there seemed less effort to bridge the intervertebral space The width and number of trabeculae and the thickness of cortex was greater in these spurs when compared with the host bone

Vertebrae were noted with severe destruction of the vertebral end plate in which marrow spaces of the vertebral body reached the cartilage plate This change occurred in older dogs and was limited to the thinner central portion of the vertebral end plate No correlation with changes in width of the disc space or with the presence of osteophytes was noted



Fig 28 Microradiograph of a sagittal section of the vertebral end plates at disc 15 of a standard poodle (10 yr ♂) The vertebral end plates are smooth and the disc space is markedly narrowed Thickness of the compact bone forming the end plate is greater than normal (× 40)

b Tetracycline Labelling Studies

Tetracycline antibiotics administered in vivo are preferentially incorporated at the site of mineralization of bone matrix or in cartilage when undergoing calcification (Urist and Ibsen 1963) This relatively non toxic non radioactive easily administered intravital bone seeking fluorogen can be studied in properly prepared undecalcified sections The sections display a characteristic fluorescence of the tetracycline when viewed through transmittant ultraviolet light

Of the 100 dogs with spondylosis deformans 15 were given tetracyclines prior to death In addition 7 normal control dogs were labelled Most of the affected dogs were terminal clinical cases in which tetracyclines were administered therapeutically In those labelled for the purpose of this investigation the dose of antibiotic ranged from 30 to 66 mg/kg bodyweight, and it was given intravenously Chlortetracycline hydrochloride was the drug most commonly used The time period between administration of the drug and death of the dog ranged from 15 hours to 12 days

If labelled with tetracycline antibiotics the 100 μ thick undecalcified sections used in preparation of microradiographs were examined with a microscope equipped with a mercury vapor lamp as the source of ultraviolet light The techniques employed in the present study were those used by Olsson and Rietz (1966)

Normal Mature Vertebrae

The normal mature vertebrae had a rather uniform pattern of labelling On sagittal sections there was scattered fluorescent labelling on the surface of both dorsal and ventral cortices and on the surface of trabeculae In compact bone only a few labelled osteons were seen

Deposition of tetracycline was uniformly distributed on the trabecular bone However only a low percentage of the surfaces were labelled There were no areas within the vertebral body with a consistently higher percentage of labelled surfaces nor were there any areas totally lacking fluorescence Surfaces of the vertebral end plates were not labelled in any sections

Forming Osteophytes

Actual growth of the spurs could be demonstrated as well as bone formation within them The latter was considered a sign of active remodelling The small amounts of calcified cartilage that constituted an early sign of osteophyte formation were labelled diffusely The manner of labelling changed with formation of a trabecular pattern Regardless of the stage of development of the osteophyte calcifying cartilage on the tip and surface toward the disc was highly fluorescent (Fig 29) The only fluorescence seen in the newly forming cortex on ventral or lateral surfaces was a well defined periosteal line (Fig 30) The notch between osteophyte and vertebral body was almost without exceptions labelled to a high degree independent of the tetracycline uptake elsewhere

Free bony segments within the ventral anulus usually possessed many labelled areas The labelling was more extensive when there was calcified cartilage on the periphery Labelling of trabeculae within the center of these islands resembled that of adjacent vertebrae

The greatest level of activity occurred when two osteophytes or an osteophyte and a free fragment were in the process of joining (Fig 30) The interspace was partially filled with diffusely labelled zones of calcifying cartilage There was active formation of bone on the surface of the bone trabeculae within the osteophyte as it continued to grow This was usually at a rate similar to that noted within the host bone However on several occasions there were more labelled surfaces on the trabeculae of the osteophyte than of the vertebra

Calcifying cartilage within small growing osteophytes on the dorsal aspects of vertebrae was labelled diffusely These osteophytes were precisely on the dorsal corner and projected only a short distance

Mature Osteophytes

As osteophytes neared a mature stage intense labelling on the surface toward the disc disappeared with formation of a more mature appearing cortex



Fig 29 Sagittal section of an osteophyte on the ventral corner of the cranial end of L7 from a German shepherd (8 yr ♀) The undecalcified bone section was labelled with tetracycline and viewed in transmittant ultra violet light The calcified cartilage surface of the osteophyte is directed toward the disc space at the upper right corner of the picture (straight arrows) The cartilage shows a marked diffuse pattern of fluorescence There are also distinct lines of fluorescence on the surfaces of bone trabeculae within the osteophyte (curved arrows) There is no tetracycline label on the ventral cortex of the osteophyte at the bottom of the picture (× 75)

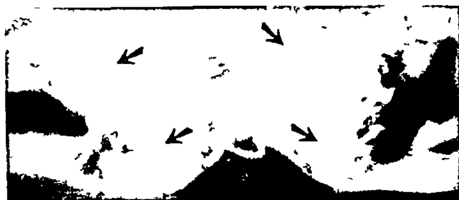


Fig 30 A sagittal section of the tips of two adjacent osteophytes at disc 14 from a German shepherd (6 yr ♀) The undecalcified bone section was labelled with tetra cycline and viewed in transmittant ultra violet light The calcifying cartilage on the surface and that extending between the tips of the osteophytes has a marked fluorescence (arrows) The loose ligamentous tissue covering the ventral surface of the osteophytes is wrinkled There is a thin but distinct fluorescent line on the ventral aspect of both osteophytes indicating some appositional bone growth (× 75)

The last area to possess fluorescence was within the notch Marked labelling at this point could be seen when all other parts of the osteophyte appeared mature The degree of fluorescence on trabecular surfaces and cortices was similar to the host bone at this stage

Debris

Amorphous mineral deposits were identified in the ventral anular area These possessed a diffuse pattern of fluorescence These foci were identified on microradiographs and had the appearance of amorphous calcified masses

c Conventional Histologic Studies

Bone adjacent to that used for undecalcified sections was taken for conventional histologic examination Usually the sagittal sections included the ends of two vertebral bodies and the disc between them However the large size of some specimens necessitated removal of the dorsal portion of the vertebral bodies and of the disc In these sections only the ventral parts were examined

Specimens were fixed in 10 per cent solution of aqueous neutral formalin They were decalcified through use of 5 per cent nitric acid and embedded in paraffin. Staining on 6 μ sections included hematoxylin and eosin van Gieson s picrofuchsin hematoxylin and Toluidine blue

Transverse sections of intervertebral discs were made from 11 dogs using the method described by Hansen (1952) This technique maintained shape of the disc and resulted in least damage to the histologic preparations All regions of the vertebral column and all stages of growth of vertebral osteophytes were included

Development of Vertebral Osteophytes

The following description was based mainly on the sagittal sections Earliest changes observed were multiple small foci of fibrocartilage between the outer lamellae and the longitudinal ligament These foci occurred either adjacent to or slightly away from the vertebral corner However most commonly they occurred at the point where the vertebral body outermost anular fibers and ventral longitudinal ligament came together If foci were not adjacent to the vertebrae stages of increasing size were noted until contact was made with the bone Small blood vessels were seen within the newly formed fibrocartilage (Fig. 31) Bone was formed around these vessels by osteoblasts apparently in direct contact with the walls of the vessels Additional formation of bone occurred at the margin of cavities that were seen to connect with marrow spaces of the osteophyte (Fig 32) Many of the smaller cavities became filled with bone and the appearance was similar to that of an osteon The larger



Fig 31 Area of fibrocartilage adjacent to the forming osteophyte within disc 13 of a German shepherd (12 yr ♀) Vascular spaces have small amounts of bone around them H & E (× 100)





Fig 32 Edge of an osteophyte at disc 26 of a *mongrel* (*10 yr* [illegible] fibrocartilage is at the upper right of the picture Next is a layer of [illegible] with small bony islands To the left of the picture is more [illegible] H & E (× 100)

Fig 33 Free segment of bone within the collagenous tissue [illegible] disc 6 in a German shepherd (6 yr ♀) The segment [illegible] numerous smaller ones To the left of the bony segment [illegible] top of the picture are the outer anular lamellae At the [illegible] longitudinal ligament. H & E (× 20)

cavities which were connected with marrow spaces developed thicker zones of bone but still retained a rather large central cavity The osteophyte increased in size toward the disc through continuous formation of cartilage and sub sequent bone formation The newly formed bone appeared mature Immature bone was not noted (Fig 32)

The ventral longitudinal ligament was displaced in a ventral direction by the growing osteophytes A tissue rich in collagen fibers filled the space between the outermost lamellae of the anulus fibrosus and the ventral longitudinal ligament In some cases collagenous tissue created a massive bridge between two opposing osteophytes (Figs 33 34 A 35 36) When there was only one osteophyte at an intervertebral space the collagenous mass had a more irregular shape The size of this collagenous mass increased in direct relationship to the increase in size of the osteophytes In contrast to the normal anulus fibrosus the newly formed tissue between anular fibers and ventral longitudinal ligament contained blood vessels in small numbers (Fig 33)

An identical pattern of bone formation as described above was noted in isolated areas between the anulus and longitudinal ligament Cavities appeared within cartilaginous foci and formation of bone followed in many of these *islands (Fig 33)*

Frequently large masses of calcified debris were seen in the newly added collagenous tissue They were either isolated or partially incorporated in the developing segments or osteophytes (Fig 36)

Formation of bone on the ventral and lateral surfaces of the osteophyte did not occur in the manner just described Bone was formed from the cambium layer of the periosteum covering these surfaces

The earlier described notch around the periphery of the vertebral end plate was found in almost all sections It was usually filled with fragments of bone necrotic cartilage and anular fibers (Figs 34 35 36)

Active growth of the osteophyte as well as signs of inactivity were noted in sections taken from dogs of all ages In apparently non growing osteophytes there was no further formation of bone at the junction between the fibro cartilage and osteophyte The fibers from the newly added collagenous tissue attached to the osteophyte in a manner not unlike that seen between the anulus and the vertebral end plate The groove was seen in various stages of repair and finally achieved complete healing and became smooth

Changes in the Anulus Fibrosus

The normal anulus fibrosus was basophilic with strongest stainability close to the nucleus pulposus and to the cartilaginous plate or vertebral end plate The degree of basophilia diminished toward the outer parts of the disc The lamellae had a fish bone pattern and were separated by a small amount of basophilic *staining material with granular appearance*



Fig 34 A Sagittal section of ventral portion of disc 9 and adjacent vertebrae of a mongrel (11 yr ♀) Stage three osteophytes are on both vertebrae The layer of additional collagenous tissue (between arrows) is seen ventral to the ruptured and separated anular lamellae H & E (× 7)

B Detail of osteophyte on left side of A A notch is present (arrow) and separation of anular lamellae is marked A zone of fibrocartilage is to the right of the advancing surface of the osteophyte Ligamentous tissue is ventral to the forming osteophyte H & Γ (× 20)

C Detail of the notch seen in B Bone is on the left of the picture and anulus to the right Necrotic tissue partially fills the notch H & E (× 100)

D Detail of the osteophyte on the right side of A The notch is filled with bone that has been partially avulsed (arrows) Large spaces resembling marrow cavities are seen within osteophyte H & E (× 20)



Fig 35 Sagittal section of disc 7 of a German shepherd (6 yr ♀) and osteophytes on both associated vertebrae and a free lying segment of bone (arrows) within the added collagenous tissue ventral to the anulus fibrosus H & E (× 6)

Fig 36 Sagittal section of disc 19 of an Irish setter (13 yr ♀) There are stage three osteophytes on both vertebrae There is a large necrotic focus in the center of the added collagenous tissue (arrow) Ruptures of the anular lamellae are present H & E (× 6)

The first noticeable change appeared predominantly in the ventral anulus fibrosus The normal fibrous structure became more homogeneous and failed to take the stain as well as before (Fig 37 D) These changes were haphazardly distributed and of varying extent Within the same sections strongly basophilic foci appeared both within and between the lamellae (Fig 37 A B) In several cases similar appearing foci stained strongly acidophilic The foci were usually well delineated and consisted of debris In addition to these discrete foci many lamellae had diffuse areas with more basophilic staining properties

The three types of change just described did not regularly appear together Often the discretely appearing foci were noted within lamellae that were normal in appearance Affected lamellae were usually located ventrally but were also found dorsally in the disc

Another obvious change that appeared early was a separation of lamellae by a basophilic granular material (Fig 37 D) This filled the interlamellar space at first but wider separation resulted in formation of spaces that appeared empty on the slides (Fig 38)

A proliferation of cartilage cells was seen both within and between the lamellae (Fig 38) These cells were isolated or in groups Vacuoles of unknown genesis which appeared empty on the slides were noted within the lamellae

Ruptures of individual anular lamellae were often seen These ruptures were located within or near the necrotic foci or could occur in lamellae with more diffuse changes (Figs 34 A 37 D 38) Broken ends of the lamellae tapered and were curved They presented the appearance of a taut line that had snapped with ends recoiled backwards The majority of ruptures were near the center of the lamellae and not at the attachment to the vertebral body There were some obvious exceptions in which the breaks took place just at the attachment or only a short distance from the vertebrae In more severely altered discs ruptures in several lamellae together formed fissures of various lengths through the anulus These sometimes became large enough to extend from the nucleus to the outer few lamellar fibers (Fig 38) It was obvious that these outer rings were less affected by degenerative changes than the inner ones Frequently the intradiscal fissures extended just to the outer lamellar fibers No bulging of the anulus was noted in these cases

Origin of the necrotic debris within and between the lamellae could not be positively determined In some sections the basophilic acellular masses appeared to be a part of the degenerated lamellae (Fig 37 A B C) Serial sections often indicated that these masses were not a part of a winding track that led from the nucleus

Metaplasia of fibrocytes into chondrocytes within the anulus occurred within the anular lamellae adjacent to the vertebral end plate In more extensive cases piles of chondrocytes extended well into the disc (Fig 39)



Fig 37 A B C D Typical changes within the anulus fibrosus H & E (× 80)

In advanced cases the remaining intact anular lamellae were bent inward toward the nucleus rather than curving normally toward the outside of the disc

A most advanced degree of degeneration appeared to be the result of a grinding that took place between two adjacent vertebral bodies Direction and



Fig 38 Section of badly damaged anulus fibrosus with fissure formation from disc 17 of a dachshund (12 yr ♀) H & E (×25)



Fig 39 Section of the attachment of the anular lamellae to the vertebral end plate of disc 11 from a mongrel (15 yr ♀) There is an increase in number of chondrocytes within the anulus H & E (× 100)

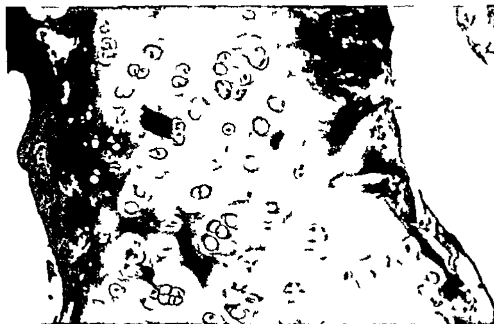


Fig 40 Section of cartilage plate from disc 15 from a standard poodle (10 yr ♂) The cartilage plate is thickened and the chondrocytes appear in columns The vertebral end plate is on the left of the picture and the cavity formation on the right is associated with the nucleus H & E (× 100)

pattern of the lamellae became so disoriented that little recognizable tissue was present In some discs the direction of the ruptured lamellae was parallel to the vertebral end plate instead of perpendicular to it (Fig 38)

Changes in the Nucleus Pulposus

The nucleus pulposus in dogs of the non-chondrodystrophoid breeds had cells with a vesicular appearing cytoplasm Intracellular substance was sparse with few collagen fibers Loose fibrosus tissue separated groups of cells into lobules This formation was more noticable in the periphery of the nucleus Cells within the lobules became more densely basophilic As the dog aged the cytoplasm in the cells diminished in quantity However the amount of collagen rich fibrous tissue between the lobules increased greatly In some sections formation of cells similar to fibrocartilage cells was noted at the periphery of the nucleus pulposus

In dogs of the chondrodystrophoid breeds formation of a chondroid tissue was *widespread and usually occupied the entire nucleus In some sections* peripheral portions of the nucleus appeared to have undergone more change than the central portion Parts of the nucleus pulposus became necrotic and calcification of the chondroid tissue was common The perinuclear portion of the anulus fibrosus also had cellular changes that were similar to those found within the nucleus This made distinction between the two major parts of the disc difficult In some cases nucleus pulposus underwent complete calcification and/or necrosis

Portions of the nucleus appeared to have protruded either partially or completely through the anulus

In contrast to the changes in the anulus fibrosus changes in the nucleus pulposus showed a definite pattern in their development Still the degree of change within the nuclei in discs of the same dog was not identical

Changes in the Cartilage Plate

The degenerative changes seen in the cartilage plate were minimal when compared with the other portions of the disc Changes in the thickness of the plate were rare In some discs the border between the cartilage plate and anulus fibrosus was made diffuse by greatly increased production of chondrocytes and matrix The matrix often stained darkly indicating calcification Streams of large vacuolated cells in columns perpendicular to the cartilage plate extended into the disc (Fig 40) These cells sometimes formed large foci and contained up to 10 or 12 distended chondrocytes with pyknotic nuclei This cartilage tissue met with cartilage cells in the nucleus The resulting mass fused with the vertebral end plate and calcified in some discs This sequence of events took place more commonly in the chondrodystrophoid breeds

Fissures in the cartilage plate or intraspongeous herniation were not noted In rare cases there was a wedge shaped indentation of the cartilage plate with no evidence of associated bone formation This did not appear as the so-called ossification gap but only as a depression in otherwise normal vertebral end plates

Changes in the Longitudinal Ligament

Necrotic areas were also observed within the ventral longitudinal ligament These were usually small and resembled the homogeneous areas in the anulus fibrosus described above They were not common and were not located in a specific region of the ligament There was no subsequent formation of bone seen at these locations

4 Correlation Between Changes Within the Intervertebral Articulation

It is well known that spondylosis deformans is not the only condition associated with the articulations between two contiguous vertebrae Disc degeneration disc protrusion and arthrosis of the costo vertebral and vertebral synovial joints were repeatedly found during dissection Pathogenesis and significance of spondylosis deformans might be better understood if it were known how these changes were related to each other and to the vertebral osteophytes Changes found in the intervertebral disc costo vertebral and vertebral synovial joints and the presence of spondylosis deformans were recorded in the 96 dogs thoroughly dissected

Morphologic appearance of the intervertebral discs was classified as normal maturation (Group A) or as having signs of degeneration (Group B) (Page 13) Protruded discs were recorded separately and their incidence was evaluated as one of the end results of disc degeneration

Costo vertebral and vertebral synovial joints were evaluated as normal or degenerated (Page 14) Neither stage of degeneration nor number of de generated articular surfaces at the intervertebral space was considered

One osteophyte at the intervertebral space was considered a sign of involve ment regardless of stage of development

The material was not separated into breeds because of low representation within most breeds However a division into chondrodystrophoid and non chondrodystrophoid breeds was made using Hansen s (1952) classification These breed groups were divided according to sex This resulted in formation of the following groups

non chondrodystrophoid — female
non-chondrodystrophoid — male
non-chondrodystrophoid — total

chondrodystrophoid — female
chondrodystrophoid — male
chondrodystrophoid — total
female — total
male — total

The following major relationships were studied on an intrasegmental basis within each individual group and within the total material

vertebral osteophytes — arthrosis of vertebral synovial joints
vertebral osteophytes — arthrosis of costo vertebral joints
vertebral osteophytes — intervertebral disc degeneration
vertebral osteophytes — disc protrusion (Type I)
vertebral osteophytes — disc protrusion (Type II)
arthrosis of vertebral synovial joints — arthrosis of costo vertebral joints
arthrosis of vertebral synovial joints — intervertebral disc degeneration
arthrosis of costo vertebral joints — intervertebral disc degeneration

The interrelationships between vertebral osteophytes changes in vertebral synovial joints and changes in intervertebral discs were also studied for the three major divisions of the vertebral column

Results

The results of the intrasegmental comparisons were recorded as Pos (positive) or No (no correlation) (Table 1) There were no instances of negative correlation If the correlation was positive the level of significance was recorded in the table Statistical evaluation could not be performed in all regions because of low frequency or absence of change

C Discussion

Materials

Statistical evaluation was performed on the material that was randomly selected from the Pathology Department of the Royal Veterinary College The breed distribution was compared with the breed distribution within the Stockholm dog population in 1961 (Backgren and Henricson 1964) It was shown that the boxer was over represented to a highly significant degree (χ^2 = 13 92 d f = 1) The poodles were evaluated as a composite group and were under represented in the selected material to an almost significant degree (χ^2 = 4 30 d f = 1) There was no other significant difference in breed distribution between the dog population and the necropsy material Backgren and Henricson showed that the distribution of breeds within a clinical material was

Table 1 Intrasegmental Correlation of Changes within the Intervertebral Articulations

Changes	Chondrodystrophoid Breeds			Non-chondrodystrophoid Breeds			Total	Total	Total
	Female	Male	Total	Female	Male	Total	Female	Male	
Vertebral Osteophytes + Vertebral Synovial Joint Arthrosis	Pos	No	No	Pos	Pos_3	Pos_3	Pos_3	Pos_3	Pos_3
Vertebral Osteophytes + Costo vertebral Joint Arthrosis	No	—	Pos	Pos	Pos_4	Pos_3	Pos	Pos	Pos_3
Vertebral Synovial Joint Arthrosis + Costo-vertebral Joint Arthrosis	No	—	No	Pos_2	No	Pos_2	Pos_3	Pos_1	Pos_3
Vertebral Osteophytes + Disc Degeneration	No	Pos_1	No	Pos	Pos_3	Pos	Pos_1	Pos_3	Pos_3
Vertebral Synovial Joint Arthrosis + Disc Degeneration	—	No	No	Pos	Pos	Pos_3	Pos_2	No	Pos
Costo vertebral Joint Arthrosis + Disc Degeneration	No	—	No	Pos	Pos	Pos_1	Pos_3	No	Pos
Disc Protrusion (Type I) + Vertebral Osteophytes	No	Pos	Pos_1	No	No	No	No	Pos	No
Disc Protrusion (Type II) + Vertebral Osteophytes	No	No	No	Pos_3	Pos_3	Pos	Pos_3	Pos_4	Pos
	n=468	n=286	n=754	n=936	n=806	n=1 742	n=1 404	n=1 092	n=2 496

	Chondrodystrophoid Breeds				Non chondrodystrophoid Breeds				Total	Total	Total	Total
	Cervical	Thoracic	Lumbar	Total	Cervical	Thoracic	Lumbar	Total	Cervical	Thoracic	Lumbar	
Vertebral Osteophytes + Vertebral Synovial Joint Arthrosis	—	No	No	No	—	Pos_3	Pos_2	Pos_3	—	Pos	Pos	Pos_3
Vertebral Osteophytes + Disc Degeneration	No	No	No	No	No	Pos_3	Pos_3	Pos	No	No	Pos	Pos_3
Vertebral Synovial Joint Arthrosis + Disc Degeneration	No	No	No	No	No	Pos	Pos_3	Pos	No	No	No	Pos_3
Disc Protrusions (I + II) + Vertebral Osteophytes	—	No	No	No	—	No	Pos	Pos	—	Pos	Pos	Pos
	n=145	n=377	n=232	n=754	n=335	n=871	n=536	n=1 742	n=480	n=1 248	n=768	n=2 496

Pos = Positive correlation
No = No correlation

1 = Level of significance $0\,05 > P > 0\,01$
2 = Level of significance $0\,01 > P > 0\,001$
3 = Level of significance $0\,001 > P$

representative of the normal population within the immediate area of the respective clinic The over representation of boxers was probably due to a selection of cases from the clinical material The reason for this selection could not be explained The slight difference in distribution of the poodle breeds might not have been a real difference since the three poodle breeds were taken together as a composite group

All dogs examined were mature and they were older than the general population Sex distribution of the dog population in Stockholm for 1953 and 1956 has been studied (Krook 1956) The difference in sex distribution between the randomly selected material and the general dog population was not significant (χ^2 = 1 99 d f = 1)

No cases of osteomyelitis primary bone tumor severe congenital or development anomaly or post traumatic change within the vertebrae were identified Three dogs with radiographic evidence of metastatic spread of neoplasia to vertebrae were excluded

Methods

Macroradiographic and gross examinations were of value in determining frequency location and gross morphologic appearance of vertebral osteo phytes The addition of microradiographic tetracycline labelling and conven tional histologic techniques enabled a more detailed study of the structure and pathogenesis

Classification of osteophytes into stages for purpose of recording was subjective but provided a workable method for recording their size and shape The stages did not represent a quantitation of the osteophytes That is stage four did not represent an osteophyte two times as large as stage two Also osteophytes of the same stage had masses that varied widely

The objective recording of stages of degeneration of the intervertebral disc as determined grossly was not always substantiated by histologic examination It was seen that relatively normal appearing discs often had rather severe microscopic changes

Incidence and Causes of Its Variation

The incidence of spondylosis deformans reported in the present study was 61 2 per cent In earlier reports the incidence has ranged from 9 to 75 per cent It is obvious that many factors influence this incidence

In the present study the incidence of spondylosis was reported as it related to age sex and breed In order to evaluate the interplay of these factors it has been necessary to make further statistical calculations that are discussed in this section

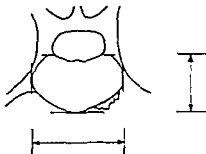


Fig 41 Illustration demonstrating that two radiographic projections of the vertebral body will not demonstrate an osteophyte positioned on the ventro-lateral aspect of the vertebral body

Methods of Investigation

The method of investigation affects the incidence greatly

Some reports have not included examination of the entire vertebral column (Morgan *et al* 1966) Other studies utilized radiographic examinations of the intact dog by routine lateral and dorso ventral projections (Pommer 1933)

In the present study it was noted repeatedly that small osteophytes located on the ventro-lateral margin of the vertebral body were not projected on macroradiographs The reason for this was obvious when the vertebra was examined (Fig 41) Also a small osteophyte could escape detection on the macroradiograph even though it was located on the ventral midline In the cat Beadman *et al* (1964) thought that 15 per cent of the osteophytes found in post mortem examinations were not visible on routine lateral radiographs The present study suggested that a higher percentage may be unnoticed in the dog

An examination of necropsy material will also result in changes passing unnoticed unless ventral musculature is thoroughly removed from the vertebral column Failure to do this may result in a sizable error in determination of the number of osteophytes in the cervical cranial and caudal thoracic and cranial lumbar regions This was probably the reason why Hansen (1952) reported a distribution and frequency of osteophytes that differed from that reported in the present study

Age

The present study gave evidence that the incidence of spondylosis deformans in dogs increases with age This fact has been reported earlier (Pommer 1933 Ipolyi 1939 1941 Schick 1942 Debard 1949 Fankhauser 1955 Morgan *et al* 1966 Read 1966)

This increase in incidence of spondylosis deformans with age did not necessarily mean that there were more or larger osteophytes in older dogs The average number of the osteophytes per vertebral column was almost the

same in the group 4 to 10 years of age as in the group over 10 years of age Also the size of the osteophytes did not increase markedly in older dogs

From these data it would seem that most of the formation of the osteo phytes took place during what might be considered 'middle age' of the dog Also some osteophytes progressed with age to stages four and five at the same time other new osteophytes were forming. The 'average size of the osteophytes thus remained constant

Exceptions to this pattern were recognized A few older dogs had no osteo phytes conversely others had widespread changes within the first years of life

Sex

The observed equal sex distribution was in agreement with earlier studies in the dog (Pommer 1933 Ipolyi 1939 1941 Hansen 1952 Martin 1959 Read 1966) but contrary to those who have reported the male to be more susceptible (Fankhauser 1955 Martin 1958) or the female to be the more susceptible (Morgan *et al* 1966)

The average age of the sex groups is known to greatly affect incidence This seems to have been overlooked in most earlier reports It was discussed by Morgan *et al* (1966) and ruled out as a cause of higher incidence in the female The mean age in years in the present study was 7 45 (±3 78) for the males and 8 40 (±3 10) for the females The difference between the ages was not significant (t = 1 46 d f = 114) Therefore age did not influence the finding of an equal sex frequency

Breed

The incidence of spondylosis deformans within the three breeds most highly represented was evaluated without reference to number of osteophytes per vertebral column There was no significant difference in incidence between these three breeds

The mean age of the three groups was determined to be 7 15 (±3 67) years for the German shepherds 8 26 (±2 45) years for the boxers and 9 75 (±3 23) years for the dachshunds There were no significant differences between the ages of the groups of boxers and German shepherds and between the ages of the groups of boxers and dachshunds (t = 0 96 d f = 30 t = 1 73 d f = 41) There was slight significance between the age of the groups of German shep herds and the dachshunds (t = 2 13 d f = 35)

When the incidence of spondylosis and the mean age of the groups were compared it was seen that the dachshunds were significantly older and had a slightly greater incidence of spondylosis deformans Therefore the higher age in the dachshund group probably caused the slightly greater incidence of spondylosis deformans as compared to the group of German shepherds

There was an almost significantly higher frequency in the heavier dogs following division of the material by weight Each weight class was divided into age groups to evaluate the affect of age When comparison was made between the frequency of spondylosis deformans within four weight classes in each age group no significant differences were found (χ^2 = 0 37 4 89 2 17 d f = 3) When comparison was made between the three age groups in each weight class there was significance within the <10 kg class (χ^2 = 9 05 d f 2) an almost significant difference within the 20 1 to 30 kg class (χ^2 = 7 70 d f – 2) and no significant differences in the other two classes (χ^2 = 2 30 3 93 d f – 2) Thus the significance noted following division into weight classes probably was due to unequal distribution based on age

Hansen s definition of chondrodystrophoid breeds was used as a basis for division of the material This included the group of dogs that have shown themselves to be particularly exposed to disc degeneration The common denominator for these breeds was then discovered to be a pattern of endo chondral ossification similar to that found in chondrodystrophy in man In the present material the dach hund French bulldog and pekingese breeds re presented the chondrodystrophoid group

No significant difference in incidence was found between the chondrodystro phoid and non-chondrodystrophoid breeds The mean ages of the two groups were determined to be 9 83 (±1 83) for the chondrodystrophoid group and 7 75 (±3 34) for non-chondrodystrophoid breeds This difference was highly significant (t = 4 20 d f = 114) The frequency of spondylosis was the same in two breed groups one of which was significantly older If the two groups were composed of dogs of equal ages the chondrodystrophoid breeds might have had a lower frequency

Hansen (1952) found that disc degeneration in chondrodystrophoid breeds usually led to type I protrusions without associated spondylosis deformans Degeneration in discs of dogs of non-chondrodystrophoid breeds as well as in discs of old dogs of chondrodystrophoid breeds resulted in protrusions of type II and/or spondylosis deformans The average age of the material in the present study was older than that in Hansen s study and this may make the result of direct comparison unreliable However the findings in the present study do not contradict Hansen s results

The severity of spondylosis within breeds was also evaluated on the basis of number of osteophytes per vertebral column and the size of the osteophytes This was only done in the three most highly represented breeds boxer, German shepherd and dach hund

Within the boxer breed the dogs had significantly greater numbers of osteophytes per vertebral column Also there was a higher frequency of the

stages of larger osteophytes No significant difference in age between the boxer and other two breeds was noted

The German shepherd breed had dogs with more and larger osteophytes than the dachshunds and yet the dachshunds were older to a significant degree

The dachshunds had the fewest and smallest spurs and had the highest mean age of the three groups This was in agreement with Hansen s findings that chondrodystrophoid breeds were less prone to spondylosis than were non chondrodystrophoid breeds

The present study indicated that if the size and number of osteophytes were considered there would be a difference in breed predisposition to spondylosis deformans This was in agreement with the reports describing a high incidence of spondylosis deformans in the boxer (Glenney 1956 Schnitzlein and Martin 1957 Martin 1958 Schnitzlein 1960 Zimmer and Stahli 1960 Morgan *et al* 1966)

Distribution of Osteophytes

In the present study the pattern of distribution throughout the vertebral column was slightly different from that noted in earlier investigations Read (1966) reported the only study in the dog showing the incidence of osteophytes in the caudal thoracic region to be as high as the commonly reported peak at the lumbo sacral junction Read included in her definition of osteophytes bony changes that were not recorded as osteophytes in the present study

The ventro lateral location of most bony spurs in the caudal thoracic region was the probable cause of the low recorded incidence of osteophytes there Also the presence of overlying ribs made radiographic detection of small osteophytes difficult Osteophytes in the lumbar region were generally midventral and were therefore more easily identified

The incidence and size of osteophytes relative to the cranial and caudal aspects of the vertebrae of the dog was studied and no consistent pattern was noted

The location of osteophytes on the ventral and lateral vertebral margins in the present study was in a bilaterally symmetrical pattern

Examination of the distribution of vertebral osteophytes suggested that they were not randomly positioned Specific patterns were obvious throughout the vertebral column and on each individual vertebral margin

Dorsal osteophytes were rare in the present material The presence of dorso lateral spurs related to costal facets transverse processes of thoracic vertebral bodies or large lateral osteophytes was more common The absence of dorsal osteophytes was striking in cases with extensive new bone growth present in

all other areas around the vertebral margin No cases were found in which osteophytes had encroached on the spinal canal to an appreciable extent

Dorsal osteophytes have previously been reported in the dog Many of these osteophytes were identified on a lateral radiograph and were not verified surgically or during necropsy It is quite possible that dorso lateral osteophytes calcified disc protrusions or ossification of the dura mater have been errone ously diagnosed as dorsal osteophytes

Relation of Vertebral Osteophytes to Disc Degeneration

Anulus fibrosus

Changes within the anulus fibrosus appeared to play a major role in the development of vertebral osteophytes In many discs earliest changes were focal lesions in the anulus and these progressed to major intradiscal fissures These changes were noted more commonly in the ventral aspect of the disc and were an almost constant finding in discs with associated osteophytes However the changes were also found in discs without osteophytes and dorsally in discs with osteophytes The size and shape of the osteophyte did not always correspond to the extent and degree of change within the disc

The more severe disc changes consisted of further damage to already ruptured anular lamellae and a noticeable increase in the amount of debris within the disc In advanced cases the disc tissue had almost disappeared and naked bone of adjacent vertebrae was ground and appeared almost polished This narrowing of the disc space appeared to have followed rather than preceded the early formation of osteophytes

Hansen (1952) described changes in the anulus fibrosus that were related to dorsal disc protrusions These changes were similar to the ones reported in the present study However intradiscal fissures within the ventral lamellae appear not to have been described in relation to spondylosis deformans in the dog

The outer anular fibers consistently appeared to have been affected to a lesser degree than the remaining portions of the anulus The reason for this is unknown

Nucleus pulposus

The nucleus pulposus did not seem to play an important role in the patho genesis of spondylosis deformans Changes in the nucleus pulposus similar to those described by Hansen (1952) were noted They consisted of chondroid and fibroid metaplasia within the chondrodystrophoid and non chondrodystro phoid breeds respectively

Contrary to the findings of Hansen a slight positive correlation was observed in the intrasegmental relationships between type I protrusions and vertebral osteophytes in chondrodystrophoid breeds Again this may have reflected the effect of age in the present material Further examination of intrasegmental pairs within the chondrodystrophoid breed group indicated almost no correlation between degeneration and calcification of the nucleus and vertebral osteophytes The degeneration of the nucleus pulposus in the chondrodystrophoid breeds occurs at a younger age preceding the damage to the anulus This lack of correlation suggests that degeneration of the nucleus in the form of calcification does not appear to stimulate the formation of vertebral osteophytes

Hansen (1952) thought that spondylosis deformans was a morphologic expression of more advanced disc degeneration There have been others who have also considered the pathogenesis of spondylosis deformans to be directly related to disc degeneration (Ipolyi 1939, 1941 Schick 1942 Fankhauser 1948) However Martin (1959) described early spondylosis in the dog associated with discs that were normal in gross and microscopic appearance

The findings of the present study strongly suggested that changes in the anulus fibrosus were far more important in the pathogenesis of spondylosis deformans than changes in the nucleus pulposus Hansen (1959) suggested that changes in the nucleus pulposus were primary causes of all pathologic changes in the intervertebral space Whether the anular changes described in the present study were preceded by nuclear changes or not was difficult to determine

Cartilage Plate

The cartilage plate was less degenerated than other parts of the disc and showed no change in some discs However this structure seemed to play a part in compensating for a loss of nuclear material and a great increase in the width of the cartilage plate was often noted This could account for the observation made from radiographs that narrowing of a disc space associated with disc protrusion is not permanent After some time normal or almost normal width is again noted (Olsson 1966)

Correlation of Changes within the Intervertebral Articulation

The possibility that vertebral osteophytes were correlated to other changes in the intervertebral articulation was considered The intrasegmental correlations for the total material were positive for all but one pair The same pattern held for the totals of the non-chondrodystrophoid breeds The opposite pattern was found within the chondrodystrophoid breeds where positive correlations were rare

The pairs of changes with no correlation in the total breeds and non chondrodystrophoid breeds involved type I protrusions These were extremely rare in the non-chondrodystrophoid breeds and lack of correlation was probably due to this low number of protrusions

The correlations that were strongly positive may have indicated an inter relationship between the various changes within the intervertebral articulations However it was also possible that changes were related independently to a third factor such as increasing age The material was not sufficiently homo geneous to permit formation of age groups to examine whether any change occurred independently of and earlier than the others

Changes could also be correlated to disorders in another organ or system of the body Necropsy reports on all dogs were thoroughly examined and there was no single condition that could be related to changes in the intervertebral articulation However there was no comparable control material with which to compare statistically the necropsy results of the investigated material

The two positive correlations found in the totals of the chondrodystrophoid group were at a low level of significance Disc degeneration in the two breed groups was of a different type Therefore it would appear that nuclear calcifica tion which comprised most of the disc degeneration in the chondrodystrophoid breeds does not have a direct relationship with other changes in the inter vertebral articulation The lack of positive correlation between changes other than disc degeneration cannot be explained

The material was divided by sexes and major regions of the vertebral column within the two large breed groups The results of these subdivisions were generally the same as the totals for the chondrodystrophoid or non-chondro dystrophoid breed groups The few differences in correlation followed no particular pattern The lack of correlation within the cervical region was probably because of the low frequency of all changes these

The results of the present correlative study were based on macroscopic observations that were only qualitative in nature If a microscopic study were conducted in which the degrees of changes were compared the result might be different

Mechanism of Formation of Osteophytes

A notch was consistently noted at the area of attachment of the outer anular lamellae to the vertebral end plate Within the notch were fragmented bone calcified cartilage and calcified debris The cartilage and debris were regularly labelled with tetracycline The impression gained was that of an avulsion of the attachment of the anular lamellae with progressive necrotic changes Concomitant with the maturing of the osteophyte the notch became smoother as the tissue was replaced by bone

Why the avulsion occurred almost exclusively at the attachment of the outer lamellae is not fully understood As described in the present study intradiscal fissures frequently extended to the level of the outermost lamellae Under these circumstances the outer lamellae were the only intact fibers remaining that could transmit a stress from the nucleus to the vertebral end plate However even when most lamellae were intact the avulsion and subsequent necrosis occurred regularly at the attachment of the outer lamellae It is thought possible that non ruptured lamellae with extensive change would be unable to effectively transmit normal stresses from the nucleus Therefore even though no lamellae were broken the outer lamellae would still represent the only physiologically intact fibers through which stress could be transmitted In either event the traction exerted upon the attachment of the outer lamellae on the vertebral end plate would be greater than normal

The vertebral end plate seemed to play no active role in formation of the osteophytes Usually no increase in the amount of bone tissue within the vertebral end plate was observed When an increase was present there were usually severe changes within the intervertebral disc This was contrary to earlier reports (Schick 1942 Hansen 1959) They stated that the sclerosis of the vertebral end plate was an end point of the pathogenesis of spondylosis deformans

In the present study thinning of the vertebral end plate more commonly was found in older dogs This also was unrelated to spondylosis deformans

Origin and Growth of Osteophytes

The exact location of the origin of the osteophytes varied slightly but was usually located adjacent to the corner of the vertebral body Multiple foci of fibrocartilage which were subsequently calcified formed and united with the vertebrae at an early stage

Ingrowth of blood vessels was followed by a destruction of calcified cartilage and a formation of a mature appearing trabecular bone This slow orderly growth led to a final stage of continuous blending of the trabecular patterns and marrow spaces between the vertebra and osteophyte

The mass of connective tissue formed between osteophytes continually provided the network on which bone tissue was formed This collagenous tissue appeared as an extension of the outer anular fibers It was definitely not disc tissue that was bulging or had been squeezed out

The multiple foci of fibrocartilage and calcified cartilage often remained unattached within the collagenous tissue that formed outside the anulus fibrosus Bone was formed within these foci Many of these bony segments reached considerable size with a mature appearance but still remained unattached to the vertebrae Others joined advancing osteophytes The macro

scopic studies did not completely rule out the possibility that the bony segments were fracture fragments However the histologic study made it possible to show the manner in which these segments were formed and excluded the possibility that they were a result of fractures

The development of vertebral osteophytes was shown to have no association with possible remnants of the epiphyseal growth plate

Formation of the osteophytes was similar in both chondro- and non chondrodystrophoid breeds

Microscopic studies showed which osteophytes and specifically which parts of an osteophyte were in the process of growing The pattern of tetracycline labelling was not equal in multiple osteophytes in the same dog Also the presence of calcified cartilage as seen microradiographically was not always associated with high levels of tetracycline uptake This indicated that growth of the osteophytes was not always continuous Signs of maturity included the blending of trabecular pattern and disappearance of calcified cartilage on the surface of the osteophytes Maturity could occur at any stage suggesting that formation and growth of an osteophyte was governed by some functional requirement When sufficient size was reached to provide the reinforcement required growth apparently ceased Whether or not new stimuli could initiate renewal of growth is not known but this seems probable

The Role of the Ventral Longitudinal Ligament

The passive role played by the ventral longitudinal ligament in initiation or pathogenesis of osteophytes was obvious in the present study The location of the osteophyte s origin in relation to the ventral midline determined whether the ligament would be stretched over the osteophyte cause a groove in the osteophyte or become surrounded by new bone The crescent form of the osteophyte indicated that there had been ventral and/or lateral pressure The longitudinal ligament and its thinner continuations laterally seemed to provide a restraining force on the osteophyte

It was observed in the present study that both ventral and dorsal longitudinal ligaments were fused to the anulus of the intervertebral disc. This is in agreement with earlier studies (King and Smith 1955 King 1956 Smith 1960) The dorsal longitudinal ligament is much heavier than the ventral counterpart and extends from the axis to the coccygeal region It forms a part of the floor of the spinal canal and displays a characteristic widening as it passes over each interspace The longitudinal ligament attaches to a greater segment of the periphery of the vertebrae dorsally because of this marked widening

In the present study the method and degree of attachment of the longitudinal ligaments to the vertebrae appeared similar both dorsally and ventrally However the fibers entered the bone dorsally at a sharper angle This point of

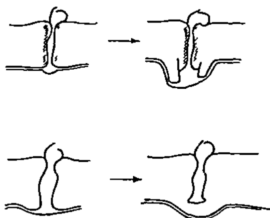


Fig 42 Diagram explaining the possible influence the longitudinal ligament may exert on the development of spondylosis deformans If the disc space is collapsed (above) the ligament will be more loosely fitting and exert less effect on the direction of growth of the new bone If the disc space is of normal width (below) the ligament fits more tightly and exerts pressure influencing the shape of the bony spur

attachment did not appear to play any part in the initiation of development of osteophytes No evidence of cellular activity at the attachments of the longitudinal ligaments to the vertebrae was noted in these studies The ventral or lateral growth of the osteophyte was uniform and from the cambium layer of the cortex and not greater at the exact point of ligamentous attachment

A thinner lateral continuation of the ventral longitudinal ligaments provided a covering for a part of the vertebral body

Osteophytes at a narrowed interspace had a different appearance The narrowing apparently resulted in a loosening of the ventral longitudinal ligament which was then unable to exert as great an influence on the shape of the osteophyte (Fig 42)

Ossification of the vertebral ligaments has been reported in the dog and the name "ankylosing spondylitis" used (Schnitzlein and Martin 1957 Martin 1958 1959 Schnitzlein 1960) The changes observed within the longitudinal ligaments in this study were minimal and resembled those found in the anulus fibrosus Ossification within the ligaments was not a part of the condition described in the present study The ventral longitudinal ligament was influential only in determining the characteristic shape of the vertebral osteophytes it did not initiate formation of them

The present morphologic study gave ample evidence that the pathogenesis of vertebral osteophytes is as follows Changes that are assumed to be degenerative occur within the ventral anulus fibrosus Stresses on the non ruptured outer anular lamellae seem to cause avulsions of their attachments

Formation of the osteophyte occurs in a fibrous tissue formed outside the anulus fibrosus Development resembles that found in normal growth of bone referred to as endochondral bone formation Changes in nucleus pulposus cartilage plate and vertebral end plate seem to be of minor importance The ventral longitudinal ligament is influential only in giving the osteophyte its typical curved shape The formation of vertebral osteophytes was shown repeatedly to be a slowly occurring non inflammatory reparative process

The findings of the present study provide ample evidence to justify the use of the term spondylosis deformans to describe this condition The common use of the term spondylitis in veterinary medicine is without justification since inflammation has no role in the pathogenesis Other terms have been suggested that indicate a degenerative character However spondylosis deformans is the most commonly used term in human medicine and has been partially accepted in veterinary medicine Therefore spondylosis deformans seems to be the term of choice for naming this condition in the dog

Radiological and Clinical Observations

A Growth of Vertebral Osteophytes

1 *Methods and Materials*

Repeated radiographic examination of living dogs was the method used for studying growth of vertebral osteophytes For this reason 25 owners of dogs with radiographically diagnosed spondylosis deformans were asked to return their dogs for re examination Of those contacted 22 agreed to participate in the study Only the previously radiographed portions of the vertebral columns were re examined The intervals between the two examinations ranged from 11 to 27 months

2 *Results*

The dogs were described and the findings were tabulated (Table 2)

3 *Discussion*

Examination of the total vertebral columns could not be made Therefore the discussion must be limited to the appearance of new osteophytes and growth of older osteophytes on the predetermined regions of the vertebral columns Macroradiographic techniques have been shown to have limitations in diagnosis of spondylosis deformans Nevertheless several conclusive observations were possible

Growth of osteophytes which were present on the first examination and/or formation of new osteophytes were seen in 15/22 (0 68) dogs These represented many breeds both sexes and ages ranging from 4 to 14 years Formation of new osteophytes during the interval between the examinations was seen in 9 22 (0 41) dogs No new osteophytes were identified in 13/22 (0 59) dogs irrespective of the appearance of the older spurs No difference in size or number of osteophytes had occurred during the interval of time between the radiographic examinations of 7/22 (0 32) dogs These were from five breeds and both sexes and their ages ranged from 2 to 9 years

4 *Conclusions*

The present study showed that two thirds of a group of dogs of widely varying ages and breeds and of both sexes had an increase in number or size of

Table 2 Observations on Growth of Osteophytes as Determined by Comparative Radiographic Studies

Breed	Age at first study in years	Sex	Period between studies in months	Stage of development of osteophyte: First study II	III	IV	V	Second study II	III	IV	V	Comment
Non chondrodystrophoid												
Airedale terrier	2	F	12		4				4			unchanged
Fox terrier	4	M	17	2					2	2		
Boxer	5	M	16	1	4	4			3	4	2	
Boxer	5	F	18	4				3	1	1		
Dalmatian	6	M	20		1				1			unchanged
Bloodhound	7	M	21	1	6	2		2	11	3		
Boxer	7	F	27	2	5	8	11	1	3	6	16	
Boxer	7	M	18		1					1		
Boxer	7	M	18	1				1	1			
Boxer	9	M	11		1	3			1	3		unchanged
Boxer	9	F	12	2	1	2		4	1	2		
Drever	9	F	13		2				2			unchanged
Standard poodle	9	M	0	1		2		1	2	1	2	
German shepherd	11	F	18	1	6	2	2	1	8	4		
Shetland sheepdog	11	F	19		1	1				2		
Standard poodle	12	F	16		2					2		
Labrador retriever	12	F	14		5	1		1	2	3	2	
Cocker spaniel	14	F	19		2				1	1		
Chondrodystrophoid												
French bulldog	4	M	18		2				2			unchanged
Dachshund	5	F	13		1			1	1			
Dachshund	6	F	15		2	1			2	1		unchanged
Dachshund	8	M	15				2				2	unchanged
			Totals	15	46	26	15 = 102	15	48	36	6 = 105	

osteophytes During the interval of time between examinations one third of the dogs had only quiescent appearing osteophytes in various stages

B Clinical Significance of Vertebral Osteophytes

1 Methods and Materials

A questionnaire was sent to 86 owners of dogs that were obtained by random selection through the Pathology Department (Group A) Dogs with and without spondylosis deformans were included Remaining owners were not contacted because of failure to obtain complete names or addresses

The following information was requested (1) Had the dog ever shown pain in the vertebral column or weakness in the hind quarters? In case of such pain describe signs treatment and recovery (2) Had the dog previously had any injuries to the vertebral column or hind legs? (3) What had been the general condition of the dog especially as related to running climbing and jumping? (4) How long had the owner owned the dog?

The cases were divided into three groups for purposes of statistical analysis One group was considered to have a 'negative history relative to the vertebral column It included all cases with negative histories and those with positive histories in which the description of pain or disability could not possibly be attributed to chronic change within the vertebral column The second group was classified doubtful It included dogs with positive medical histories in which the cause of lameness or pain could have originated from the vertebral column However the medical history or necropsy offered other explanations for the disability The third group was classified 'possible The positive medical histories suggested that pain or disability originated from the vertebral column The necropsy reports rarely confirmed this possibility but offered no other explanation for the clinical signs observed

The 22 owners of dogs that were re-examined radiographically completed the same questionnaire (Group B) A description of this material was presented earlier (Table 2) Because of the bias in selection of material no statistical evaluation was performed The questionnaires were evaluated in the same manner

2 Results

A total of 84 owners of dogs in Group A responded All except one had owned the dogs since they were puppies This indicated that the history was complete for the entire life of each dog except one

The first group with a negative history had 33/55 (0 60) dogs affected with vertebral osteophytes The group considered doubtful had a total of 7/10

(0 70) with vertebral osteophytes The third group was classified possible and included a total of 15/19 (0 79) with vertebral osteophytes

The difference in frequency of vertebral osteophytes within these three groups was not significant ($\chi^2 = 2\ 31$ d f = 2)

The medical histories of the dogs in Group B were evaluated by use of criteria presented above No dogs were classified as having doubtful histories

An increase in size or number of osteophytes was noted in 10 16 (0 62) with negative clinical signs (Group 1) and in 5 6 (0 83) in which positive clinical signs were judged 'possible (Group 3)

3 *Discussion*

Answers were frequently more detailed than necessary and included a great deal of insignificant material Inclusion of specific dates pertinent to the dog s medical history indicated a thorough knowledge and memory concerning the animal Additional comments were frequently furnished with detail and exactness

The question concerning amount of exercise was primarily to ascertain the physical condition of the dog It also indicated that each dog was exercised regularly Therefore any difference in manner of locomotion would more readily be noticed than if the dog were allowed to remain within a home or exercised unescorted

Throughout the present study continual effort was made not to under estimate the possibility that clinical signs were associated with spondylosis deformans If there was doubt concerning the origin of pain lameness or weakness it was always assumed that it could have been related to the vertebral changes

Group A

The dogs in Group A were considered to have been randomly selected from the cases presented to the Pathology Department

The interpretation of what should be considered significant pain or disability was subjective However the division of the material into three groups made it possible to draw conclusions from the data It was thought that the question naire was valid as a measure of clinical signs of pain lameness or paresis

Interpretation of necropsy findings in relation to medical histories was difficult Many cases with clinical signs of lameness or more often weakness during the last years of life had necropsy findings which could well explain the signs described These necropsy findings often included severe cardiac disease chronic renal disease or extensive spread of a malignant tumor These cases were placed in the doubtful (Group 2) category for statistical evaluation

In contrast there were medical histories in which owners made positive comments concerning physical activity of their dogs These often described dogs that had severe spondylosis deformans and had led a physically active life until time of death

Group B

The material re examined radiographically was not evaluated statistically be cause of a selection from clinical material Unexplained lameness or pos terior weakness was seen in 6/22 (0 27) dogs with spondylosis deformans Of those dogs with no clinical signs of pain lameness or posterior weakness 10/16 (0 62) had an increase in size or number of osteophytes Some of these had extensive stage four and five vertebral osteophytes

4 Conclusions

The present study offers proof that spondylosis deformans in the dog is usually present without associated clinical signs

PART IV

Experimental Production of Vertebral Osteophytes

The present morphologic study indicated that changes in the anulus fibrosus were important for production of osteophytes The following experiments were designed to test the validity of this finding

A Method and Materials

Seven young mature dogs were used for the experiment No abnormality of the discs could be found on macroradiographs of the vertebral column The thoraco-lumbar discs of 3 dogs (1 2 3) were exposed from the lateral side Three discs in each dog were punctured with a lancet and mucoid nuclear material exuded No effort was made to remove nuclear material and no curetting of the discs was performed Recovery of these dogs was uneventful

Each of the additional 4 dogs (4 5 6 7) had two different procedures performed on their intervertebral discs The lumbar discs were exposed through a mid abdominal incision All exposed discs appeared normal Five discs were subjected to experimental injury in each dog One procedure was to insert a scalpel blade transversely into the ventral anulus in such a manner that neither nucleus nor ventral longitudinal ligament was affected The other procedure was to cut both ventral longitudinal ligament and outer anulus fibers without injury to the nucleus In none of these discs did nuclear material protrude Recovery was uneventful in 3 dogs Abdominal viscera partially herniated through the incision immediately following surgery in one dog The incision was reclosed and further recovery was uneventful The period of time between surgery and necropsy was recorded (Table 3)

Following necropsy of the experimental dogs macroradiographs of the vertebral column were made using standard and multiple oblique projections Macroscopic examination was performed and tissue for conventional histologic examination was taken from the vertebral columns of 5 dogs (1 2 3 4 5) It included transverse sections of the disc Sagittal and frontal sections included portions of both vertebrae and intervening discs Sections of discs adjacent to those operated upon were used for controls The 2 other dogs (6 7) were examined macroscopically in such a way that tissues for histologic examination was not available

Specimens for microradiographs were obtained in the same manner as described previously (Page 26)

The techniques used in preparation of the histologic sections and micro radiographs were similar to those described earlier (Pages 38 26)

B Results

Macroscopic and Macroradiographic Studies

Changes around the discs operated upon were classified in three categories according to macroscopic or macroradiographic changes (Table 3) The first category included discs without evidence of fibrous tissue proliferation or osteophytes Signs of surgical intervention were easily identified in all but two discs (dog *1* disc *19* dog *2* disc *21*) The second category included discs with fibrous tissue proliferation This created a mound of firm tissue adjacent to the disc A surgical scar was noted in all of these discs The third category included discs with radiographic evidence of new bone proliferation In one case the new bone growth involved the attachments of the crura of the diaphragm The resulting osteophyte was located further from the disc space than usually seen (dog 4 disc 22)

The smallest gross changes were noted following puncture of the nucleus with a lancet The highest percentage of larger osteophytes resulted from

Table 3 Results of Experimental Production of Vertebral Osteophytes

Case number	Breed	Sex	Age in months at surgery	Post operative period before necropsy in days	Disc numbers								
					17	18	19	20	21	22	23	24	25
1	Mongrel	F	12	156	1_a		1_a		1				
2	Dalmatian	F	13	256	1		1_c		1_a				
3	Dalmatian	F	13	300	1_b		1_b		1_b				
4	Fox terrier	F	23	224					[illegible]	2_c	3_a	3_c	2
5	Fox terrier	F	23	220				2	3_c	2_b		3	2_b
6	Mongrel	F	12	220					2_b	2	3_a	3	3
7	Mongrel	M	12	217					2_c	3_c	2	3_c	3

1 = Lancet passed into nucleus pulposus through anulus fibrosus
2 = Ventral part of anulus fibrosus cut with a scalpel introduced ventro-laterally
3 = Ventral part of anulus fibrosus and longitudinal ligament cut with a scalpel

a = No gross changes
b = Formation of soft tissue mass
c = Formation of osteophyte

cutting of the longitudinal ligament and outer anulus However 2 discs treated in this manner had no gross evidence of tissue proliferation even though the surgical scar was evident All discs with injury to only the anulus fibrosus had proliferative changes but not as extensively as had the discs with additional injury to the longitudinal ligament

The nucleus was mucoid or in early stages of fibroid metamorphosis in all discs except those in which the experiment involved the nucleus The nuclei of fenestrated discs (procedure 1) were less mucoid in appearance and had lost their normal configuration They remained in the normal location except for one that had shifted in a controlateral direction (dog 2 disc 19) Occasionally minimal discoloration of the entire disc was noted (dog 2 disc 17 dog 3 disc 19) There were no gross signs of hemorrhage associated with the changes

Generally the location of changes corresponded closely with the site of the experimental lesion When the tissue proliferation was small it was located only at the point of incision

Small dorsal protrusions of type II were noted in 2 dogs (dog 4 discs 22 24 dog 5 disc 21) There was no grossly apparent compression on the spinal cord

As seen macroradiographically the operated disc spaces remained of normal width with two exceptions of narrowing No evidence of increase in the amount of bone within the vertebral end plates was noted

One operated disc (dog 1 disc 21) had severe changes that were atypical when compared with the others Macroradiographic changes consisted of destruction of the central portion of the adjacent vertebral end plates with an increase in the amount of bone surrounding the lytic areas There was associated collapse of the disc space These signs were first noted 22 days post-operatively and were interpreted as due to a discospondylitis No evidence of osteophytes was seen on the macroradiographs and the other disc spaces appeared radiographically normal Extensive palpation over the vertebral column elicited no sign of pain Radiographic changes remained essentially the same and the dog was without clinical signs during the time preceding necropsy At gross examination the affected disc was hemorrhagic collapsed and with large osteophytes on both ventro-lateral borders of each adjacent vertebrae Most severe change was at the site of surgical invasion of the disc Hemorrhagic material from the disc was cultured with a negative result

Unoperated portions of the vertebral column were negative for spondylosis deformans Vertebral synovial joints and costo vertebral joints were normal by gross determination

All of the control discs were normal on gross examination except one (dog 5 disc 26) This disc had undergone severe change with a type II protrusion resulting

All dogs were healthy active and without clinical signs of pain during the period of time between surgery and necropsy

The appearance of the osteophytes as observed on conventional histologic preparations was similar to that seen in spontaneously occurring spondylosis deformans (Figure 43 A) The experimental incision was recognized in most discs and did not involve the nucleus in discs treated by procedures 2 and 3 The severed ends of the surgically incised anular lamellae were tapered in some cases and had become deeply basophilic However none of the earlier discussed lamellar or intra lamellar changes were observed (page 43)

Focal necrosis in the vertebral end plate was identified in several sections However the changes were minimal and did not include severe necrosis and subsequent avulsion of bone fragments

The osteophytes developed through the same stages as described in the spontaneous material (Figure 43 B C) The addition of collagenous tissue ventral to the anulus was not as great as would have been expected in spontaneous cases

The microradiographs of the experimentally produced osteophytes were similar to the spontaneously occurring spurs (Fig 44) The calcified cartilage on the surface was thicker however

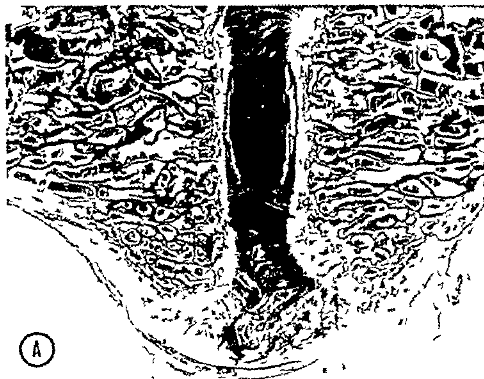


Fig 43 A Sagittal section of experimentally prod[...] disc 24 of a fox terrier (2 yr ♀) The [...]ytes are surgical incision on the anulus [...] H & E (x

B Detail of the osteophyte on the left of A but taken from adjacent tissue section H & E (× 25)

C Detail of the surface of the osteophyte in B A large number of osteoblasts are present H & E (× 100)



Fig 44 Microradiograph of a sagittal section of an experimentally produced osteophyte at disc 21 of a fox terrier (2 yr ♀) (× 50)

C Discussion

The experimental lesions in the discs and/or ventral longitudinal ligaments consistently produced vertebral osteophytes The first procedure involved minimal injury to the anulus and permitted escape of a small amount of nuclear material The longitudinal ligament was left intact In the second procedure injury was to the anulus alone In the third type of lesion the longitudinal ligament and the outer anular fibers were severed without directly damaging the nucleus

A common factor in the three procedures was an injury to the anulus fibrosus The degree of change to the anulus appeared to be directly related to the degree of bony response The associated injury to the nucleus or longitudinal ligament did not appear to alter the type of response

The operative intervention showed that surgical lesions to normal discs gives rise to vertebral osteophytes The specific mechanism causing the formation of the bony spurs was not completely understood The surgical intervention probably caused an instability of the disc This is logical when the assumed function of the anulus fibrosus is considered If this is true the damage to the nucleus or longitudinal ligament only caused further instability to the disc Selective damage to either of these structures alone is thought not to be sufficient in itself to stimulate production of vertebral osteophytes The possibility that the surgical procedure alone might stimulate the formation of osteophytes should also be considered

The minimal differences between the structure of experimentally produced and spontaneously occurring osteophytes can be explained by the more rapid growth of the former The rapid formation of the osteophyte exceeded the production of the collagenous tissue ventral to the disc The number of chondrocytes in various stages of deposition of mineral in the matrix and the number of osteoblasts were much greater than in the spontaneously affected material

Experiments have been performed in dogs (Keyes and Compere 1932 Compere and Keyes 1933 Haas 1946 Sullivan and Compton 1957 Sullivan and McCaslin 1960 Pettit 1960) and in rabbits (Lob 1933 1934 Smith and Walmsley 1951) with resulting production of osteophytes A direct comparison of these studies was difficult since the procedures were more severe and extensive than those used in the present study

Other investigators have injured the disc but subsequently stabilized the interspace Jenkner *et al* (1953) attempted intervertebral fusion in monkeys following a fenestration technique in which he carefully re sutured the anular flap Humphries and Hawk (1959) packed the disc space of dogs with bone chips and used an anteriorly placed plate to create stability Key and Ford (1948) attempted to produce posterior protrusions of the disc in dogs by

damaging the posterior longitudinal ligament and dorsal anulus fibrosus All of these experiments damaged the disc However when stability was re-established the production of osteophytes was minimal if present at all

Macroscopically observable changes in the rest of the intervertebral articulation were not noted in the experimental cases Instability of the disc may also produce an environment resulting in production of arthrosis in the vertebral synovial or costo vertebral joints If this is true it apparently requires a longer interval of time before macroscopic changes are found

The experimental studies reported in the present investigation are in agreement with earlier experimental studies However it would appear that only a small degree of trauma is necessary to create the instability within the disc that is thought to be important in production of vertebral osteophytes It is suggested that the role of the nucleus or longitudinal ligament is not as important in production of osteophytes as is the damage to the anulus

D Conclusions

Three different experimental procedures which damaged the intervertebral disc produced vertebral osteophytes The procedures all damaged the anulus fibrosus The results of the experiment support the conception that changes in the anulus fibrosus precede formation of vertebral osteophytes

PART V

Comparative Aspects

A Morphologic Appearance

The structure of spondylosis deformans in the dog was similar to the condition as it was described in man (Junghanns 1931 Oppenheimer 1942 Hirsch and Riley 1947 Bick 1952 1955 a b Bohatirchuk 1955 1957 1963 Schmorl and Junghanns 1959) In man as in the dog there were two types of osteophytes reported The most common was associated with a disc space of near normal width and had a curved shape The less common type was found around disc spaces that were narrowed and the osteophyte was less curved and more pointed (McRae 1956 Schmorl and Junghanns 1959)

Osteophytes in the bull (Thomson 1965) and in the cat (Read 1966) had a similar morphologic appearance to that noted in the dog and in man

A difference in structure was related to the amount of bone within the osteophyte Vertebral osteophytes in the bull were described as being sclerotic (Thomson 1965) This was not noted in studies of man and the cat and rarely in the present study of the dog This finding in the bull was based primarily on macroscopic techniques

The blending of the trabecular pattern between the osteophyte and the vertebral body appeared to be more complete in man the cat and the dog than in the bull

The similarities between man and the dog are noteworthy because of postural differences and differences in shape and architecture of the vertebrae

The incidence of vertebral osteophytes in the dog increased with higher age This was in agreement with studies in man (Junghanns 1931 Roche 1957 Jonck 1961 Nathan 1962) in the bull (Thomson 1965) and in the cat (Beadman *et al* 1964 Read 1966)

In the present study there was no sex difference in the incidence of spondylosis In man there was evidence of earlier occurrence in the male with the female equally affected at an older age (Junghanns 1931) Jonck(1961) and Nathan (1962) also reported a higher frequency of spondylosis in the male Roche (1957) reported a higher incidence in the female However with increasing age the incidence in the male equaled or exceeded that in the female No sex difference was found in the incidence of spondylosis in the cat (Read 1966) In contrast the nearly complete absence of spondylosis in the cow and

the high frequency in the bull was recognized (Hansen 1956 Bane and Hansen 1962 Thomson 1965)

Differences in the incidence of vertebral osteophytes between the various races of man were described (Stewart 1947 Roche 1957 Nathan 1962) Thomson (1965) suggested that differences in breed incidence in the bull were also possible In the present study different breed incidences were found but because of the nature of the material complete information on this point was not obtained

Stewart (1958) found an increase with age in the number of vertebral *segments involved rather than great increases in size of individual osteophytes* This finding in man agrees with that noted in the dog

The similarities in structure of vertebral osteophytes in different species are more evident than the differences However spondylosis deformans in the bull does not conform to the general pattern as closely as the other species

B Pathogenesis

Both the morphologic and experimental observations in the present study suggested that changes in the anulus fibrosus lead to ruptures of its fibers This was shown to be of great importance for the occurrence of osteophytes

In man Schmorl and Junghanns (1959) reported typical tears in the outer fibers of the anulus fibrosus with resulting detachment from the vertebral rim as the change preceding osteophyte formation An explanation for the rupture of the anulus fibrosus was not given Thomson (1965) described focal changes in the anulus of the bull that were similar to the ones described in the dog He considered them of great importance for the occurrence of osteophytes However any tears or clefts noted were considered to be artifacts resulting from sectioning Ruptures of the anulus in the dog that may be similar to those noted in the bull were thought to be intravital in the present study

There are studies in man in which more widespread changes in the discs were associated with osteophyte formation (Beadle 1931 Shore 1935 Collins 1949) Read (1966) reported that many different changes in the disc of the cat could predispose to formation of osteophytes

The pathogeneses of spondylosis deformans reported in the above studies are in general agreement that a prerequisite for vertebral osteophytes is some type of change in the disc

One interesting point in the comparative discussion of spondylosis deformans is the distinct pattern of osteophytes throughout the vertebral columns of individuals of different species From earlier reports it was evident that each of the four species studied had its own characteristic pattern In man there are three reports including distribution patterns (Shore 1935 Ingelmark *et al* 1959 Nathan 1962) The highest incidence was found in the caudal thoracic

and the lumbar regions The next highest incidence was found around C5—6 In the cat there are two studies with distribution figures (Beadman *et al* 1964 Read 1966) The incidence was shown graphically in this species as a bell shaped curve with the peak at disc 13 The single study in the bull (Thomson 1965) reported two peaks on the distribution curve One was located at disc 9 and the other at disc 19 In the present study it was shown that in the dog there were two peaks of equal height One was located at disc 15 and the other at disc 26

The difference in distribution along the vertebral column of different species probably reflects a difference in the bio mechanics of the vertebral columns It could mean that factors such as posture type of physical activity and range of mobility of different segments of the vertebral column are of importance for the occurrence of disc changes These disc changes may then cause the occurrence of osteophytes It is also possible that the cause of the degeneration of the discs may be unrelated to the bio mechanical factors However once de generated the discs become susceptible to further injury This may lead to an instability in areas where stress and motion are greater and result in changes in the anulus fibrosus that lead to osteophyte formation

Either explanation of the difference in distribution patterns of osteophytes suggests the importance of bio mechanical factors in the pathogenesis of osteophytes

Another finding that supports the concept of a bio mechanical influence is the distribution of the osteophytes on the vertebral margin In man (Allbrook 1957 Jonck 1961 Nathan 1962) in the cat (Read 1966) and in the dog there was a tendency for the osteophytes to be more ventrally located in the lumbar region and more laterally located in the thoracic region This similarity in distribution pattern could possible reflect the fact that torsion of the vertebral column is almost entirely limited to the thoracic region in these species

The manner of formation of the vertebral osteophytes in man was generally reported to occur through endochondral ossification of fibrocartilagenous tissue (Hirsch and Reilly 1947 Schmorl and Junghanns 1959) However Collins (1949) reported osteophytes in man formed by sub periosteal apposition of bone Bick (1952) reported the growth to be a reactive osteogenic process and distinguished it from calcification in the vertebral ligaments Oppenheimer (1942) described osteophytes in man forming in a potential triangular space formed by the vertebral body longitudinal ligament and anulus fibrosus He stressed that new bone could not form in normal connective fibers However Bick (1955 a b 1956 a b) described the osteophytes infiltrated the ligaments surrounding the intervertebral space

Stress resulting from disc degeneration and acting on the ventral longitudinal ligaments was considered of major importance in formation of vertebral osteophytes in man (Beadle 1931 Junghanns 1931 Bick 1955a b 1956 a b Schmorl

) in the bull (Thomson 1965) and in the cat (Read 1966) discounted mportance of stress on the longitudinal ligament This was also found to rue in the dog in the present study Thomson (1965) reported the ersion of the longitudinal ligament to bone in the bull This was not found e dog in the present study or in the study of the cat (Read 1966) It has een reported in man

iere have been those who felt that the disc in man bulged or protruded thus provided a matrix on which the osteophyte developed (Collins 1949) rs described the formation of osteophytes in newly added tissue outside original lamellae (Saunders and Inman 1940 Inman and Saunders 1947) nson (1965) also described formation of new connective tissues outside disc It is possible that this new connective tissue has been mistaken for ing anular lamellae In the present study of the dog the presence of newly ed connective tissue was firmly established

ondylosis deformans as it occurs in different species seems to be closely ciated with disc degeneration The distribution patterns suggested that mic and mechanical factors are of importance in the pathogenesis

C Clinical Significance

e are studies in other quadrupeds than the dog and in man that suggest inical significance of spondylosis deformans Bane and Hansen (1962) ied vertebral changes in the bull They concluded that spondylosis de ians occurred more or less regularly in the ageing bull and was a cause of ility to serve in the older animal

iomson (1965) stated in the introduction of his study of vertebral osteo es in the bull that this was one of the causes of impaired serving ability ever only 5 per cent of his material was slaughtered because of serving ility while over 80 per cent had vertebral osteophytes

clinical significance has also been reported in cases of cervical spondy in man This may result from compression of spinal nerve roots (Clarke Robinson 1956 Teng 1960) Stortebecker (1960) and Taylor (1964) ight that osteophytes were one cause of a myelopathy due to the hindrance n adequate arterial blood supply to the spinal cord Krogdahl and Torgersen 0) and Friedenberg *et al* (1959) reported that laterally located osteophytes d impinge on vertebral arteries or sympathetic nerve plexes at the foramina ie transverse processes

umerous reports have doubted a relationship between bony changes in the ebral column of man and co-existing back pain (Cushway and Maier 1929 witz and Smith 1940 Breck *et al* 1944 Collins 1949, Allen and Lindem

1950 Colcher and Hursh 1952 Hult 1954 Bohatirchuk 1955 Fullenlove and Williams 1957 Friedenberg and Miller 1963 Bick 1963) This is in agreement with the findings in the dog

The only well documented relationship between osteophytes and clinical symptoms and signs is found in the cervical region of man The reason for this is obscure However a combination of factors such as great range of motion and the common dorso lateral location of osteophytes allows for greater trauma and irritation to occur The low incidence and ventral location of the osteo phytes in the cervical region of the dog prevents a similar syndrome

D Etiology

It has been suggested in man that any condition leading to a weakening of the vertebral body could give rise to vertebral osteophytes (Beadle 1931 Bick 1955 a b 1956 a b 1963 1964 Weinman and Sicher 1955 Bick and Copel 1952 Nathan 1962) Senile osteoporosis and metastasizing neoplasia are considered common causes of this weakness These conditions occurred only rarely in the dog in the present study

Repeated trauma that caused minute fractures to the vertebrae has also been suggested as a cause of osteophytes in man The resulting formation was then considered to be similar to callus formation (Oppenheimer 1942 1945) The changes in the dog did not have the appearance of healing fractures and no evidence of trauma to the bone was found

On the basis of the more complete studies of spondylosis deformans in the four species discussed the theory of an infectious etiology can be ruled out

A sharp line has not always been recognized in differentiating between ankylosing spondylitis and spondylosis deformans Ankylosing spondylitis in man is characterized by bony ankylosis across the true synovial joints ossifica tion of the ligamentous structures or ankylosis across the intervertebral space Uro-genital infections have been considered by some investigators to have an important role in the pathogenesis None of the changes in the vertebral column that are typical of ankylosing spondylitis were found in the dog No detailed study was made of the uro genital organs of the dogs but there was no apparent relationship between spondylosis deformans and uro genital disease

The possibility of hormonal control over production of vertebral osteophytes has been suggested (Erdheim 1931 Hájková 1965) The changes described by Erdheim are different from those seen in spondylosis deformans in the dog In comparison with osteophytes in the dog changes in hypophysectomized rats treated with growth hormone have some similarities but also marked dif ferences (Asling *et al* 1955) The manner of growth of the new bone was periosteal but as in the dog a fibrous tissue formed outside the anulus

fibrosus The possibility of hormonal influence playing a part in breed predisposition toward spondylosis deformans was not investigated in the present study

The role of disc changes in the pathogenesis of spondylosis deformans was emphasized by the present study It indicated that the cause of spondylosis deformans will not be known until the etiology of disc degeneration is determined

Summary and Conclusions

1 Spondylosis deformans was defined as a condition of the vertebral column which was characterized by vertebral osteophytes at the intervertebral spaces

2 A morphologic and experimental study of the condition *in the dog* was presented Radiological and clinical observations were included *Technics* employed were macroradiography macroscopic dissection microradiography tetracycline labelling and conventional histologic procedures

3 The morphologic study was based on 100 spontaneously affected [illegible] Incidence was determined in a randomly selected group of 126 dogs [illegible] a necropsy material

4 The incidence was higher with increasing age and the [illegible] of osteophytes on each vertebral column was greater in [illegible]

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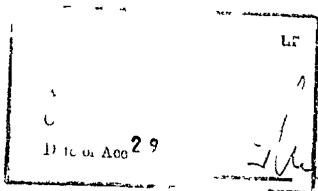
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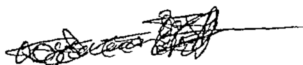
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A K SAHA

Surgery of the Paralysed and Flail Shoulder







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Surgery of the Paralysed and Flail Shoulder

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PRFFACE

While writing the monograph Theory of Shoulder Mechanism—Descriptive and Applied published by Messrs Charles C Thomas in January 1961 I had to be content in the introductory chapter with mentioning the possibilities of assessment and rehabilitation of the paralysed shoulder on the basis of the new concepts Clinical data were then insufficient to append a chapter on this

Since then more than a hundred cases of post polio flail shoulder were studied with reference to incidence distribution degree of paralysis and treatment The study is confined to the post polio paralysed shoulder which is on the wane in North America Europe and Japan with successful active immunisation against poliomyelitis It is felt that the methods described in this monograph are equally applicable in brachial plexus injuries which are unhappily on the increase in the above mentioned countries due to modern mechanisation and speed

Most of the operative procedures described in this monograph are designed to restore active mobility to the flail shoulder which would otherwise possibly be arthrodesed in presence of strong girdle muscles or disarticulated at the shoulder when the function of the distal portion of the limb is beyond the scope of surgical rehabilitation and specially if girdle muscles are weak The presence of strong girdle muscles has been shown to contraindicate arthrodesis contrary to the current belief and practice Nay even in presence of weaker muscles where arthrodesis is of little avail an actively mobile shoulder becomes a possibility

Several methods of power transfer have been tried in various combinations in flail shoulder Although a number of methods have been indicated in the text all have not been used for want of suitable cases

The results of these methods have been shown to be gratifying when the muscles to be transferred are given a proper scrutiny of their residual power and their ability assessed to replace the paralysed muscles Of course the principles underlying the mechanism of ele

vation have to be strictly adhered to while carefully selecting the surgical procedures

The results of the study were given to one of my retiring residents in 1962 for his thesis for the Master of Surgery Examination of the University of Calcutta. This he submitted in April in 1964 and therefore the statistical analysis has been omitted in this monograph

I take this opportunity to thank Dr S K Banerjee M B B S D Phys Med (Eng) Consulting Physician Physiotherapy & Rehabilitation Dept B C Roy Polio Clinic and Institute of Child Health for his help in providing most of the clinical materials and in writing the chapter on Clinical and electrical assessment of power of normal and paralysed shoulder

I convey my sincere gratitude to my Clinical Tutor Dr H Deb M B M S my colleagues Dr A K Das M B B S F R C S (Edin & Eng) Dr G K Chowdhury M B B S F R C S (Edin) and my Resident Senior House Surgeon Dr S A Momen M B B S for their ungrudging assistance to develop the operations in the cadaver and in the living

I will be failing if I do not extend my gratitude to my Senior Anaesthetist Dr Mrs A Banerjee M B B S F F A R C S and all my staff for their spade work behind the scene without whose help management of the cases would be impossible

Lastly I tender my thanks to Dr S K Dutta M B M S (Cal) and Dr A Sen Gupta M B B S F R C S (Eng) for the excellent diagrams used in this monograph and Messrs Charles C Thomas for permitting me to utilise 6 diagrams already published in the previous monograph

CONTENTS

INTRODUCTION

Paralytic sequelae of poliomyelitis are the commonest of all causes of crippling in the childhood in this country and constitute a problem of considerable importance surgically and socially In India as elsewhere the disease affects children the incidence being the highest at the age of 2 years Paralysis or weakness of one or all muscles controlling elevation of the shoulder is a common finding following poliomyelitis involving the upper extremities The usefulness of the upper limb depends to a large extent upon the ability to raise the arm from the body Such common functions as eating combing shaving and putting the hand in trouser pockets etc depend on this movement and therefore its loss results in gross diminution of functional ability of the affected limb Past workers in this field of surgery recognised the role of scapular stability while the shoulder is elevated This stability they agreed is of dynamic nature The scapular movements contribute about 33 per cent of the total elevation of 180 in a normal person In polio-affected persons we therefore expect one or all of the following deficiencies There may be incompetence in fixation of the scapula in various stages of elevation impairment or loss of the scapular rotation in antero posterior and vertical axes and its elevation with forward migration to set the glenoid surface in optimum position for the humeral head to play and lastly inadequacy of power of the muscles moving the gleno-humeral joint during elevation which most commonly presents the greatest hurdle in rehabilitation

Compensatory and alternative power in paralysis of the deltoid acting at the gleno-humeral joint is plentiful This was recognised by different workers in this field and various explanations were given for elevation in absence of power of the deltoid One of the workers Pollock developed mechanical models to explain the action of the accessory muscles and the way these help elevation in the absence of deltoid power Staples and Watkins added some new explanations All these point to the want of precise knowledge of the shoulder mechanism They could only reach the fringe of the problem on the basis of results observed clinically

Bunts in 1903 reported 7 spontaneous recoveries of abduction in a total of 19 cases. Of these though four patients did not recover their power of deltoid they could raise the arm overhead. Duchenne in 1867, Pollock in 1922 and Staples and Watkins in 1943 similarly observed and stated that the clavicular head of the pectoralis major with the help of 'Inner muscle group' could elevate the shoulder overhead in absence of deltoid power.

Though not specifically pointed out by earlier observers it is obvious that if some trick movement could raise the shoulder to about 90° in any plane the rest of abduction could be performed by the accessory muscles in absence of the deltoid. These accessory muscles are no doubt the muscles fixing and moving the scapula and the short rotators and depressors of the gleno-humeral joint. Premature girdle movement in some of these cases might be required for elevation in the initial stage of abduction.

Lewis in 1910, Payr in 1913, Gallie and Le Mesurier in 1921, Mayer in 1927 and 39, Haas in 1935 and Bateman in 1955 transferred the power of trapezius by various modifications to take over the function of the deltoid. The inherent difficulty of obtaining uniform results obviously led these workers to modify and use various techniques of trapezius transfer.

Stoffel, Mayer and Haas, who had quite a number of poor and indifferent results following trapezius transfer tried to explain this by (a) elongation of the reconstructed tendon with fascia lata (b) adhesion to the surroundings and (c) poor selection, power of trapezius being insufficient to raise the arm. Haas of his 30 cases obtained 110° abduction (defined as good result) in 12 cases. Though not mentioned separately he stated summarily that the muscles moving the scapula, pectoralis major, infraspinatus, triceps and biceps had good power in 9 cases. It is felt he must have included the remaining three short rotators, the latissimus dorsi and the teres major et minor with these. The remaining 3 cases which benefited from the operation, though this has not been stated, probably belonged to the group of 10 cases having fairly good power of accessory muscles. He did not specifically mention the role of short rotators but asserted a direct relationship between the strength of accessory muscles and the functional result, the transposed muscle being assumed to have good power.

The subluxation of the head of the humerus in post polio paralysis of the shoulder was taken up by Kiliani in 1910 and successfully treated by looping the long tendon of the biceps through a pulley made by the

folded capsule detached near the glenoidal margin and resutured to the humerus This was later modified by Nicola to a simpler procedure

Sloman in 1915 substituted paralysed middle fibres of the deltoid with the help of the long head of the triceps rerouted to the acromion process Reidel in 1928 reconstructed posterior deltoid by transfer of both the origin and insertion of the teres major to the acromion process and to the posterior surface of the shaft of the humerus respectively without disturbance to the nerve and vascular supply

Ober in 1932 Davidson in 1936 and Harmon in 1950 transferred the short head of biceps and the long head of triceps to the anterior and posterior margins of the acromion process to take over the function of the deltoid Haas reported the result of similar operation in 2 cases earlier in 1935

Hildebrandt in 1906 and Haas in 1935 reported transfer of the origin of the pectoralis major for deltoid power The patients had successful abduction to about 90

In differential paralysis of the deltoid where either interior middle or posterior fibres are paralysed with residual power in remaining fibres Moor in 1935 Harmon in 1947 and 1950 transferred anterior portion of the deltoid posteriorly and posterior fibres of the deltoid anteriorly to obtain the function of the deltoid as an abductor

Harmon in 1950 stressed the importance of the latissimus dorsi when available taking it posteriorly to the lateral lip of the bicipital groove after detaching it from the medial margin in front of the teres major This according to him helped external rotation of the limb necessary during elevation in the coronal plane

Unlike that in the gleno humeral joint the reserve is less in number in paralysis affecting the girdle muscles moving the scapula Fortunately this is compensated by the comparatively rare incidence of complete paralysis of these muscles The cause of this low incidence is not definitely known Many of these muscles have multisegmental innervation Relative inactivity during the incubation prodromal and febrile stages may be an added factor Restoration of scapular fixation and mobility in paralysis during elevation of the shoulder was taken up by various workers The various disabilities that may occur are a) dropping of the shoulder due to weak trapezius rhomboids levator scapulae and unopposed action of the serratus anterior (b) failure to rotate the scapula in the antero posterior axis due to paralysed serratus anterior with gross winging of the scapula (c) inadequate balanced power of the force couple to rotate the scapula with the arm fixed in

partial abduction(here there is no winging of the scapula but the arm cannot be raised beyond a certain range due to the inability of the scapula to rotate) (d) failure to lift the scapula bodily upward and move forward on the chest wall due to paralysis of the trapezius and levator scapulae on one hand and pectoralis minor and upper fibres of serratus anterior on the other and (e) failure of fixation of scapula when deltoid contracts with supraspinatus to initiate the elevation

Fortunately the aforesaid conditions have been rare in our group of cases The correction of the deficiency mentioned in (a) has been done by bony fixation (Spira 1948) This corrects the deformity of the scapular drop but removes the possibility of the valuable accessory movements even with the best of his modifications during elevation

Brockway in 1939 Lowman in 1963 (interscapular fascial transplant) fixed the affected scapula to give stability to the glenoid by tying both scapulae together with fascia lata nearest to the centre of the rotation of the scapula This gave good results in their hands because it does not deprive the scapula of the residual movements during elevation Whitman in 1932 fixed the vertebral border of the scapula by four fascial strips

Brunnstrom in 1941 devised methods of shoulder blade fixation in severe cases to help the initial stage of abduction This fixation is necessary for essential adjustment in the setting phase of the scapula during movement up to 60 The methods outlined above help scapular stability correct deformity and indirectly in some help movements if there is residual power with the help of contralateral girdle

Restoration of the mobility of the scapula and thus of the girdle has been devised from time to time by either muscle transfer or fixation of the scapula by fascial strips to the active muscle to help movement in desired directions

The movements of the accessory joints have their role in the elevation of the arm Impairment of the function of the muscles which bring about these movements has attracted attention of the earlier workers and they found the methods of restoration of these movements Normally rotation of the scapula in the antero- posterior axis on the thoracic cage is done by the force couple formed by lower six digitations of the serratus anterior on the one hand and trapezius (upper middle and lower fibres) on the other The upper digitations of the serratus anterior and levator scapulae and rhomboid major et minor are mainly the stabilisers of the shoulder blade while elevating the arm

The rotation of the clavicle is done by subclavius and by inevitable

force transmission from movement of the scapula Therefore the paralysis of the subclavius does not necessarily handicap the rotation of the clavicle during elevation

Elevation and forward migration of the shoulder blade are done by trapezius levator scapulae pectoralis minor and the upper two digitations of serratus anterior Their paralysis invariably drops the scapula It rolls forwards as well when there is weakness of the rhomboids

Dickson in 1937 fixed the scapula with the paravertebral group of cervical muscles by a strip of fascia lata and with the 1st thoracic spinous process by a second strip This in his cases helped partial correction of the paralytic scoliosis and improved the stability of the scapula Similarly he tried to fix the inferior angle of the scapula with strips of fascia lata to pectoralis major and latissimus dorsi to give transmitted mobility in cases of paralysed serratus anterior and rhomboids Durman in 1945 restored the power of serratus anterior by using the lower third of the pectoralis major detached from its insertion and fixed through a hole in the lower angle of the scapula Tubby earlier in 1904 tried to restore the power of the serratus anterior with the help of the sternal portion of the pectoralis major divided into 4 or 5 digitations and sutured to serratus anterior near its insertion Chaves in 1951 used pectoralis minor to replace the power of serratus anterior Herzmark in 1961 tried to improve the residual rhomboids function by reattachment of their insertion outward with trapezius overlapping Haas quoted by Lindstrom and Danielsson rerouted teres major detached from its insertion to the 5th and 6th ribs at the level of the origin of the serratus anterior This gave good results in isolated paralysis of the serratus anterior Steindler in 1954 reported cases where he used levator scapulae to the acromion to replace the paralysed upper trapezius He used pectoralis major and/or minor to the lower angle of the scapulae to act as one limb of the torque to help the rotation of the scapula in antero posterior axis

Lastly when the girdle muscles were strong and the patient unable to elevate the arm they performed various forms of shoulder arthrodesis in optimum position though results were far from satisfactory The largest series was studied by Barr et al in 1942 amongst 142 cases 101 cases had shoulder fusion The prerequisite of a fusion operation in his opinion is good power in serratus anterior and trapezius This explains the low figure of success in this series Only 10 per cent gave good results

Arthrodesis in children is discouraged by all on the basis of (a)

failure of the fusion (b) tendency to bend downward at the (i) joint line and (ii) epiphyseal line and (c) possible growth disturbance after fusion

The foregoing discussion conclusively proves that the surgical rehabilitation of a paralysed shoulder was approached without full knowledge of the shoulder mechanism. Trial and error procedures were followed with indifferent results. The approach was negative. We find quite a number of patients having flail shoulders who are discouraged to have any surgical rehabilitation and if at all they are given the benefit of arthrodesis. This monograph is intended to place surgical rehabilitation on a scientific basis anatomically, functionally and to some extent mathematically. Indeed this leads to a positive approach to the problem of flail shoulder. Quite a number of hopeless cases who were unsuitable for arthrodesis and in whom disarticulation would possibly be seriously considered have been rehabilitated quite successfully.

BIOMECHANICS OF SHOULDER MOVEMENTS FUNCTIONAL CLASSIFICATION

Multichanneled electromyograph enabled to obtain precise state of contraction of different muscles acting on the girdle and gleno humeral joint *during elevation overhead in different planes against gravity*. All the muscles of the two groups contract during elevation overhead in any plane. The rise of the action potential which denotes their increase in strength is not simultaneous but phasic.

How this phasic rise of strength of different muscles help elevation was not fully understood, neither their role at each instant of elevation worked out. The studies were mostly static instead of dynamic.

An attempt has been made to explain this phasic contraction of different muscles acting on the gleno humeral joint and their importance and therefore which of these can be dispensed with without loss of function of the joint.

This has been made possible by (a) re-evaluation of the electromyograph of muscles of the gleno humeral joint published earlier in a monograph by the author (b) study of a large group of cases with varying degrees of residual paralysis following poliomyelitis affecting one or all the muscles of the gleno-humeral joint (c) study of the functional restoration of elevation against gravity by multiple muscle transfer (d) electromyographic study of the transferred muscles during

verhead elevation against gravity in the sagittal and scapular planes nd correlation of their new action with those of the muscles having imilar action in a healthy joint

Before embarking on the discussion on the biomechanics the relevant features of the shoulder mechanism may be recalled briefly to appreciate the action of the forces bringing about the desired elevation

The ratio of the contributions of the gleno humeral and the scapulo thoracic joints when the arm is brought to the final overhead position s 2 1 i e for 180 the movement of the scapula contributes 60

Stability is as important as the mobility of the girdle and gleno humeral joint These are inseparable The gracefulness of movements s obtained only when they act in full co ordination disturbance in any of them not only takes away the available power but the scapulo-humeral rhythm is lost even in the presence of adequate power to lift the shoulder overhead

The shoulder joint is a multiaxial joint The articular surface of humerus is nearly exhausted when the arm is raised to 90 in the scapular plane Without allowing the arm to rotate outwards to change the position of the limb in space the final overhead position cannot be reached During elevation in the forward sagittal plane the rotation of the arm takes place in the opposite direction Elevation overhead in the backward sagittal plane is not possible Mechanical block by the acromion process and the adjoining spine of the scapula prevent elevation beyond 80 Thereafter it has to come to a more forward plane by gliding of the humeral head on the glenoid This gliding and or rolling is translated into external rotation of the arm till the final common position of the arm is attained The precise action can be understood if it is borne in mind that the change over of the contact surface as the arm is elevated in any plane to the overhead position would eventually bring the contact point in the neighbourhood of the lesser tuberosity (zero position)

The upper end of the humerus has got its axis set at an angle with the axis of the shaft Therefore the movement of the distal end of the humerus is not exactly what is happening at the articular surface For instance in external rotation there is forward gliding and/or rolling of the humeral head and the reverse in internal rotation with the arm by the side (Figures 1 and 2) In the zero position however when the mechanical and anatomical axes coincide the movements of the articular end is directly transmitted to the distal

The glenoid is retrotilted corresponding to the retrotorsion of the



Figure 1 Shows diagramatically the rotation of the arm in the vertical hanging position

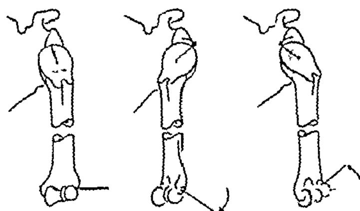


Figure 2 Showing the effect of the rotation of the arm in the vertical position in clockwise and anti clockwise direction The axis of the head and neck is seen after section through the oblique plane passing through it The contact point is seen changing its position by gliding anteriorly and posteriorly

head of the humerus Thus the general inclination of the joint surfaces forming the gleno-humeral joint is less anterolateral owing to backward tilt with reference to scapular plane in the anatomical position of the arm This inclination of the gleno humeral joint helps backward elevation to about 80

Elevation overhead converts the retrotorsion of the humerus into relative antetorsion which necessitates the adjustment of the glenoid articular surface by upward tilt forward migration and elevation With

relative antetorsion there is also greater need of backward rolling and or gliding to prevent the tendency to spontaneous forward subluxation Thirdly the natural backward tilt of the glenoid helps retaining the head on the glenoid in this near vertical position

The action of the muscles of the shoulder joint complex described in the text books is in relation to the anatomical position of the arm They do not state the functional changes which they undergo at each instant of motion in a particular direction in a joint with such versatile range of movements

The muscle which in a particular position has got certain action changes its function with elevation and at the end its action may be what would look like an opposite movement subscapularis is an example It is an internal rotator when the arm is by the side When elevated it becomes an external rotator towards the end In the vertical overhead position the upper end of the humerus is its mirror image with the arm by the side The relative position of the lesser tubercle the site of the insertion of the subscapularis gradually becomes internal to the mechanical axis This is exactly reverse in the vertical hanging position of the arm the lesser tubercle is external to the mechanical axis Therefore it is quite natural that this would in the vertical overhead position be translated into what would appear as external rotation of the arm The action of all axio scapulo claviculo humeral group of muscles acting on the gleno humeral joint changes continuously during elevation overhead

(a) *Electromyography in the Normal*

The pattern of muscle activity was studied in 1955 in several normal subjects with usual precautions for recording The recording was done with the help of an eightchannel electronic phalograph (Grass instruments model IIID 535) adopted for electromyography Vertical calibration for amplitude in milli volts and speed calibration for time in milli seconds were done before recording The angle of elevation of the limb was not recorded with the help of simultaneous photographs due to technical difficulties The limb was elevated at a uniform controlled speed during recording The period of activity in the electromyograph was divided equally into six parts at 30° intervals (from 0° to 180°) There were slight individual variations The representative muscle activity during elevation was published in 1956 and 1961

During abduction (Figures 3 and 4) in the coronal plane supraspinatus and deltoid are elevators The power is maximum at 120° and

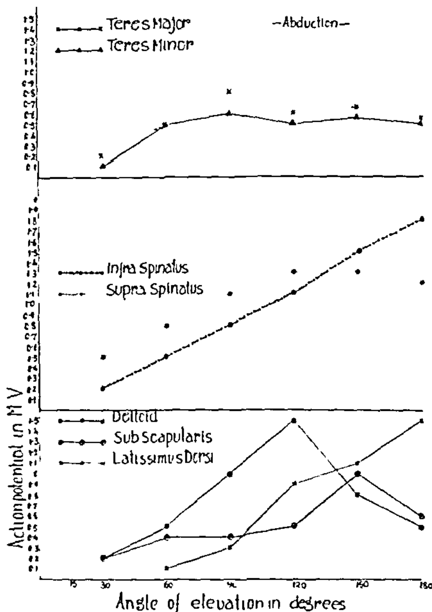


Figure 3 Showing the action potential in milli volts of axio scapulo-claviculo humeral group of muscles during abduction from 0 to 180 (Saha A K Theory of Shoulder Mechanism—Descriptive and Applied Springfield Ill Charles C Thomas Publisher 1961 Reproduced by courtesy of the Publisher)

steadily decreases reaching their minimum at 180 Subscapularis shows increasing activity from 120 -150 when its power is maximum Thereafter the power steadily diminishes to 180 of elevation The rise of power is almost exponential between 60 -150 Infraspinatus and

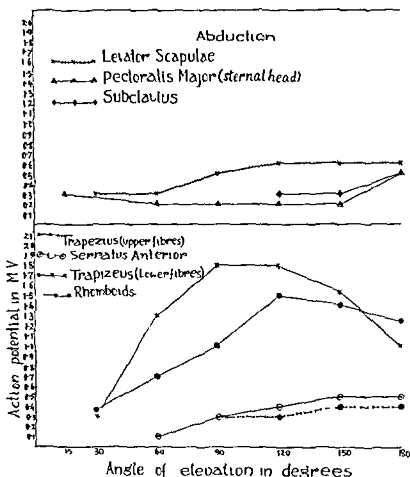


Figure 4 Showing the action potential of axio-claviculo scapular group of muscles including pectoralis major during abduction from 0 to 180 (Saha A K Theory of Shoulder Mechanism—Descriptive and Applied Springfield Ill Charles C Thomas Publisher 1961 Reproduced by courtesy of the publisher)

teres minor show maximum activity towards the end of elevation (180) Pectoralis major (sternal head) latissimus dorsi and teres major show more or less identical activity which is maximum at 180 Clavicular head of pectoralis major shows no activity (Table 1)

During elevation in the sagittal plane (flexion) (Figures 5 and 6) the clavicular head of pectoralis major shows development of power which is comparable with that of deltoid during abduction Subscapularis similarly shows development of action potential reaching its peak at 120 These two muscles are therefore sagittal elevators their action

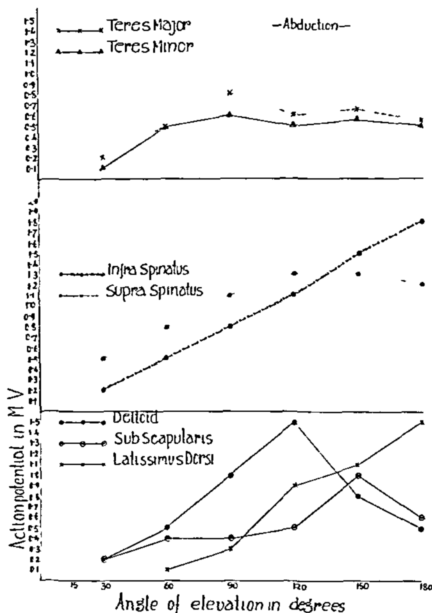


Figure 3 Showing the action potential in milli volts of axio scapulo-claviculo humeral group of muscles during abduction from 0 to 180 (Saha A K Theory of Shoulder Mechanism—Descriptive and Applied Springfield Ill Charles C Thomas Publisher 1961 Reproduced by courtesy of the Publisher)

steadily decreases reaching their minimum at 180 Subscapularis shows increasing activity from 120 –150 when its power is maximum Thereafter the power steadily diminishes to 180 of elevation The rise of power is almost exponential between 60°–150 Infraspinatus and

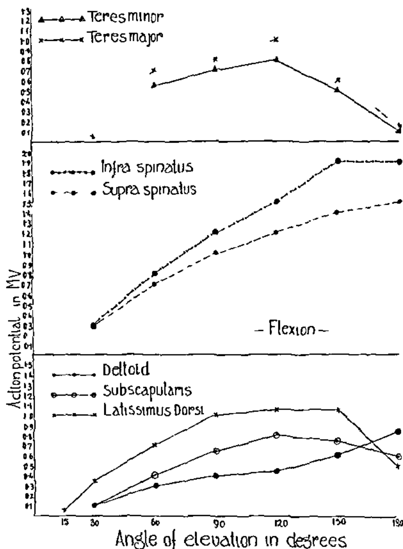


Figure 5 Showing the action of axio scapulo claviculo humeral group of [illegible] during flexion from 0 to 180 (Saha A K Theory of Shoulder Mech[illegible] Descriptive and Applied Springfield Ill Charles C Thomas Publ[illegible] Reproduced by courtesy of the Publisher)

of discharge in electromyographic tracings confirms this [illegible] the supraspinatus rises *pari passu* with the deltoid [illegible] maximum at 120 wherefrom it steadily declines to 1[illegible] capularis power shows a steady increase from 120 till [illegible] attained at 150 Thereafter it shows a slight decline [illegible]

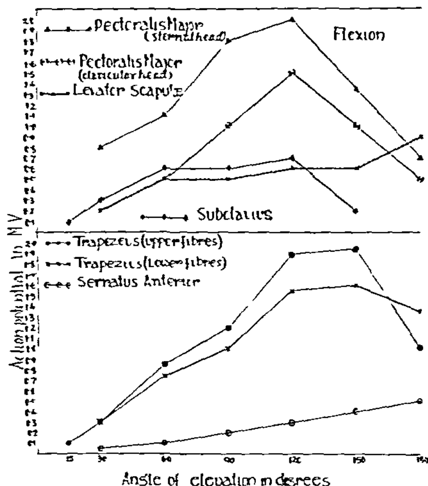


Figure 6 Showing the action potential of axio-scapulo-clavicular group of muscles including pectoralis major during flexion from 0 to 180 (Saha A K Theory of Shoulder Mechanism—Descriptive and Applied Springfield Ill Charles C Thomas Publisher 1961 Reproduced by courtesy of the Publisher)

mechanical disadvantage when its action is taken over by the intra spinatus whose power steadily increases to 180 Thus its action is helpful to the subscapularis and keeps the head in the socket which otherwise would tend to dislocate owing to relative antetorsion of the head neck of the humerus in the overhead position of the arm

In flexion the subscapularis shows continuous rise to its maximum at 120 just as the clavicular part of pectoralis major and deltoid (anterior fibres) rise to their maxima The supraspinatus and infraspinatus which steer the head show delayed rise of action potential which is maximum at 180 and 150 respectively

Table 2 Activity of Gleno Humeral Group of Muscles During Flexion in Sagittal Plane

Muscle	Onset of activity	Minimum steady activity	Increasing activity	Maximum activity	Maximum steady activity	Declining activity	Cessation of activity
Deltoid	45	45 –120	120 –180	180			
Subscapularis	40		40 –120	120		120 –180	
Supraspinatus	30		30 –180	180			
Infraspinatus	30		30 –150	150	150 –180		
Teres Major	40		40 –120	120		120 –175	175
Teres Minor	60		60 –120	120		120 –175	175
Latissimus Dorsi	20		20 –120	120	120 –150	150 –180	
Pectoralis Major (Clavicular Head)	30		30 –120	120		120 –180	
Pectoralis Major (Sternal Head)	30		30 –120	120		120 –180	

Though it has not been possible to prove it experimentally indirect evidence in support of the action of the infraspinatus in the later phase of elevation is available In total paralysis of all three short rotators replacement of supraspinatus and any one of the remaining two gives adequate steering force to elevate the arm overhead It may be either a reconstructed short rotator acting from behind or from the front Secondly in recurrent dislocation of shoulder where subscapularis has lost some of its effective power from elongation of its tendon and/or anatomical defect in the anterior hemiring of the glenoid reinforcement by a strong posterior glider acting from behind (latissimus dorsi) helps the infraspinatus to steer the head and prevent recurrence of shoulder dislocation Thirdly electromyographically the power of infraspinatus continues to rise from 150 to 180 during abduction while subscapularis shows a relative fall In flexion similarly the power of infraspinatus shows a high level of maintenance of action potential and that of supraspinatus continues to rise during this range of elevation proving that both these muscles act as posterior gliders

The intermediate group of muscles are pectoralis major (sternal head) latissimus dorsi teres major and teres minor In the *anatomical*

position none of these muscles runs the shortest course for its insertion to the shaft of the humerus All these muscles are inserted between the innermost short rotators and the outermost elevators pectoralis major (clavicular part) *cum* deltoid In the phase of near vertical elevation the mechanical axis almost coincides with the anatomical axis of the shaft the rotation of the head is directly transmitted to the shaft This intermediate group of muscles besides adjusting the final position by rotation act as strong depressors of the head to bring about the last few degrees of elevation Their obliquity downwards helps the depressor action In abduction their power either maintains a plateau or rises continuously (latissimus dorsi) from 150° to 180 Pectoralis major (sternal head) shows a rise of action potential though to a lesser extent while remaining comparatively quiescent in the earlier phase till 150

In flexion all the four muscles have a fall of action potential from 150 to 180 This fall is due to the difficulty of raising the arm by its depressor action in the plane which is different from that in which the muscles act to their best advantage Relative overaction of the supraspinatus infraspinatus and subscapularis shows that the steering of the head requires more power than elevation in the scapular plane (abduction) possibly owing to lack of adequate power from the intermediate group

The outer group comprises the pectoralis major (clavicular head) and the deltoid These are primarily concerned with giving adequate power for lifting heavy weights It may be noted that the clavicular head extends its insertion to the anterior part of the deltoid impression These muscles act their best when the steering muscles are active

(b) *Observations in Post polio Paralysis*

103 cases with residual paralysis of the muscles of the shoulder following poliomyelitis were studied Cases with complete paralysis of the muscles moving the gleno humeral joint showed absolute helplessness even in presence of good girdle muscles Cases with paralysis of the deltoid and retention of some residual power in the short rotators and depressors were not all helpless Some of them could raise the arm overhead in flexion unaided if the power of the clavicular head of pectoralis major was retained In others when the arm could be raised through the critical angle of 60 -90 with a little jerk the remaining arc could be lifted with ease Cases without presence of any depressors

could also raise the arm overhead They all confirm the views held by Duchenne Pollock Staples and Watkins and Bunts Briefly stating if the limb can be raised in any plane by active power or trick movement to 90 rest of the elevation is carried out by the active short rotators

(c) *Functional Restoration in Post Polio Paralysis*

Cases with complete paralysis of the muscles moving the gleno humeral joint were studied after restoring the deltoid and two of the short rotators (1) a vertical rotator (to replace supraspinatus) and (2) either an anterior (to replace subscapularis) or a posterior (to replace infraspinatus and teres minor) short rotator These cases were rehabilitated to lift the arm overhead in the sagittal and scapular plane None of these can elevate the limb backward even through a few degrees for obvious reasons The muscles that were chosen for transfer depended on their availability without compromising the efficiency of girdle movement They were trapezius levator scapulae sternocleidomastoid upper two digitations of serratus anterior latissimus dorsi and pectoralis minor in various combinations This simplified system of the gleno humeral joint gave excellent material for electromyographic study and provided confirmatory evidence of minimal requirements for elevation overhead against gravity in any plane

(d) *Electromyography after Functional Restoration by Multiple Muscle Transfers*

Simultaneous recording of action potential of 3 different muscles was studied with specially adapted electroencephalograph (model 6 Grass instruments) during vertical elevation in the scapular and sagittal plane through 180 against gravity For this purpose the patient was seated on a stool Three disc electrodes were placed to take the recording of the transposed muscles These three outputs were fed separately to 3 of the 8 channels of the E E G and with another common electrode the body was earthed Simultaneous recording of the action potential of the 3 muscles during elevations was done The elevation was carried out in the scapular and sagittal plane at constant speed by previous practice Calibration for sensitivity and time was made before each recording (Table 3)

G B (Figures 38 and 39 p 72) had trapezius levator scapulae and latissimus dorsi transferred for deltoid supraspinatus and infraspina

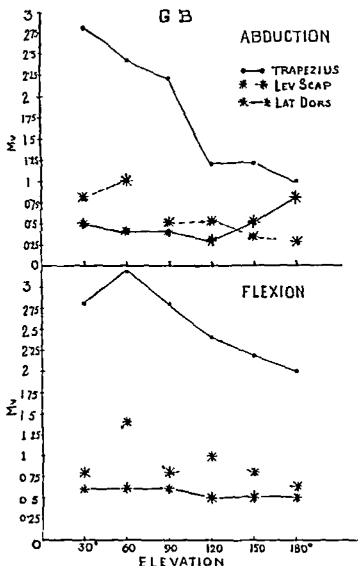


Figure 9 Shows variation of action potential of the electromyographs shown in Figures 7 and 8 To avoid overcrowding action potential above 0 2 mv noticed with the commencement of elevation is not shown between 0 and 30

tus The subscapularis power was not replaced In abduction trapezius shows the maximum rise at 30 with a steady decline to 180 Levator scapulae shows steady rise of power to 60 thereafter declines at 90 maintaining a steady minimum to 180 Latissimus dorsi shows a minimum activity to 120 thereafter it shows a steady rise till it is maximum at 180 In flexion trapezius shows a later rise of maximum

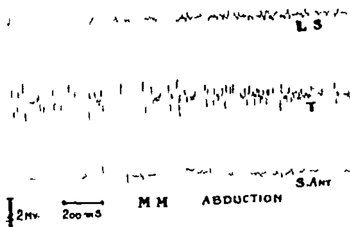


Figure 10

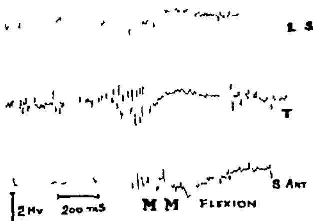


Figure 11

Figures 10 and 11 Simultaneous r cordings of rerouted trape ius levator scapulae and upper two digitations of serratus anterior during elevation ov erhead against gravity in the scapular and sagittal (forward) plane at constant speed Standardisation for action potential 1 cm = 2 milli volts and for time 1 2 cm = 100 milli sec

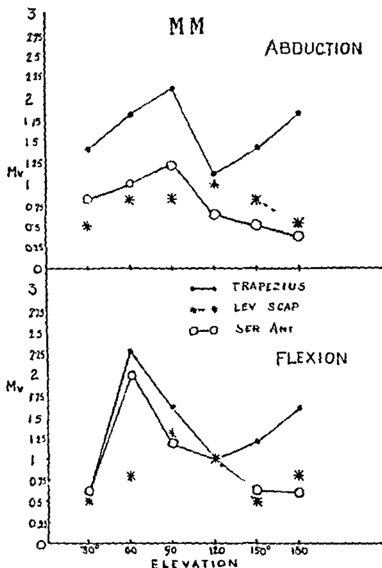


Figure 13 Shows variation of action potential of the electromyographs shown in Figures 10 and 11 To avoid overcrowding action potential above 0 2 m v noticed with the commencement of elevation is not shown between 0 and 30

power though the pattern is just like that of abduction The levator scapulae shows rise at 60 and again at 120 Though the power dec lines from 120 to 180° yet it is twice as much as that in abduction Latissimus dorsi rises to the maximum at 60 and maintains a slightly declining but steady activity to 180 (Figures 7–9)

M M (Figures 51 to 54 p 80) had trapezius levator scapulae and

upper two digitations of serratus anterior transferred for deltoid supraspinatus and subscapularis In abduction trapezius shows maximum rise till 90 and again a slightly less second rise at 180 The declining phase of activity is between 90 –120 Levator scapulae shows a steady rise from 0 to 120 and thereafter it shows a decline to its minimum at 180 The serratus anterior shows rise from the beginning to its maximum at 90 thereafter it shows a steady decline to its minimum at 180 In flexion the serratus anterior shows rise of power at an earlier phase at 60 from where it declines to its minimum at 180 The levator scapulae shows a distinct later rise to its maximum at 90 maintaining its strength till 120 thereafter after declining a little at 150 it shows a terminal rise at 180 (Figures 10–12)

These prove that in abduction the trapezius harnessed for deltoid acts as a prime mover It requires a short rotator (levator scapulae or sternocleidomastoid) to fix and glide the head in the scapular plane The action is synchronous with the action of the transferred trapezius After elevation through 60 to 90 the other short rotator comes into play It helps further elevation by posterior gliding rolling of the head This may be by a muscle acting from the front (serratus anterior or pectoralis minor) or from behind (latissimus dorsi) This is seen by the later rise of action potential irrespective of the muscle chosen They may show certain irregularities in contraction even after training as evidenced by terminal rise of the action potential in some transfers

In flexion overhead the pectoralis minor or two digitations of serratus anterior show earlier rise of action potential synchronous with the anterior fibres of trapezius The levator scapulae gives a later rise In case of a posterior glider a terminal rise is seen which is consistent with the rise expected when infraspinatus is active

Plea for Functional Classification of Muscles

The power distribution for the gleno humeral joint is at three levels Firstly three muscles exert their power at the junction of head neck and shaft axes Secondly an intermediate group of four muscles exert their power on the upper fourth of the axis of the shaft and thirdly the outer deltoid acts in three directions with the help of the clavicular part of the pectoralis major at the junction of the upper and middle third of the axis of the shaft of the humerus In a system where the proximal end (fulcrum) has to glide on a surface producing each time a new area of contact of the joint surfaces from which the arm has to

be elevated two types of power are necessary The effective steering power which should be close to the end of the head neck axis has better control over the proximal end and thus over its gliding phase of elevation This also helps in fixing the head at the constantly changing point of contact The lifting power on the other hand should act as far away from the joint as possible on the anatomical axis of the shaft Though this power has a minor role in fixing the head on the glenoid and on gliding it is more concerned with providing adequate motor power for lifting The intermediate group of four muscles act both as fixators on the glenoid and also help gliding (depressor action) Their power can be dispensed with without any apparent disability though the performance of the limb in lifting heavy weights above the head would lessen

Thus functionally the muscles moving the gleno humeral joint may be subdivided into three groups

(a) *Prime movers*—These are deltoid and clavicular head of pectoralis major Their function is to give power in lifting
(b) *Steering group*—These are short rotators subscapularis supraspinatus and infraspinatus These primarily steer and fix the head of the humerus with a minor contribution in giving the lifting force to the arm
(c) *Depressor group*—These are pectoralis major (sternal head) latissimus dorsi teres major and teres minor These muscles are rotators of the shaft of the humerus during elevation and depress the head to help the last few degrees of elevation overhead They do have however certain minimal steering action on the head of the humerus

Though the teres minor anatomically belongs partly to the short rotator group its electromyographic changes conform more to the intermediate group and therefore it is included with these

MATHEMATICAL CORROBORATION OF THE ACTION OF VARIOUS MUSCLE GROUPS

The variables in lifting the arm overhead are (a) the power development in short rotators intermediate group and prime movers in different phases of elevation (b) the range of shortening of each muscle dur-

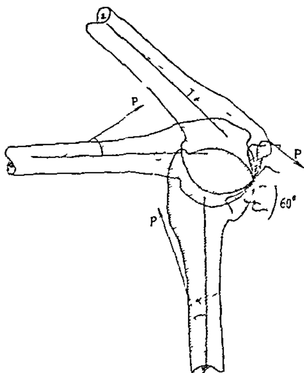


Figure 13 The figure shows diagramatically the effect of elevation on the angle which the prime mover (P) makes with the mechanical axis at different stages of elevation For clarity the different mechanical axes have not been shown owing to the constantly changing position of the axis humerus and scapular glenoid The scapular relation contributes about 60 of the total elevation

ing the isotonic phase of contraction and thus its role in the movement of the humerus (c) variable angles which the short rotators depressors (intermediate group) and prime movers bear with the constantly changing mechanical axes of the shaft and of the head neck in space at each instant of elevation and (d) co ordination of the girdle muscles steering muscles and the intermediate group of muscles (depressors) to set the joint surfaces in optimum position to facilitate elevation The last is primarily governed by the central nervous system(cortex) gained after training in infancy and in the present state of our knowledge is beyond the scope of possible mathematical correlation

The joint surfaces are not perfect spheres The centre of curvature of the glenoid (G) of the humeral head (O) and the contact point (C) are thus not colinear during elevation and add to the complexity of the problem

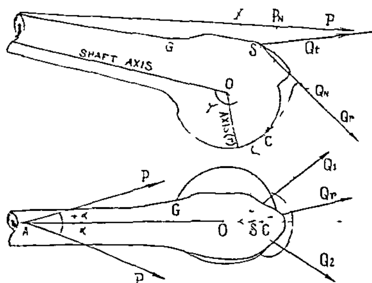


Figure 14 The diagram shows the various forces taking part during elevation of the shoulder in the sectional view in the plane of the scapula The lower diagram shows the plan projection view with distribution of forces

From the biomechanical standpoint this can be simplified to the study of effects of forces (a) in the scapular plane and (b) in the plane at the right angle to (a) (plan view) Such idealising simplification does not represent the actual state of affairs It enables us to arrive at the effects of different types of forces on the gleno humeral joint

In the sectional view in the scapular plane (Figures 13 and 14) the articular surface of the humerus is capable of moving through an arc of about 155 The contact point C changes its position and bears an angle of ω with the axis of the shaft Therefore ω = 35 + angle formed by gliding of the head while lifting from the side In a particular position the contact point C may coincide with the axis of the head neck whose centre of curvature is at O The radius of curvature of articular surface *i e* between C and O is r and in one position CO coincides with the axis of head neck Let the force contributed by prime mover be P acting at A on the axis of the shaft of the humerus Let Qr be the short rotator force acting during elevation in the plane of movement at S OS may be taken for all practical purposes equal to r As the arm is raised from hanging position to vertical overhead position the angle which P bears with the shaft axis in different position has the nature of a half of sine curve *i e* its value is minimum when it hangs by the side and reaches its peak when the arm is elevated to 90

and again declines when the arm is elevated to vertical overhead position In arriving at this we have to take into consideration the maximum rotation of the scapula around the anteroposterior axis The lifting mechanical advantage will depend on $Qr \times CQ_N$ and $P \times CP_N$ CQ_N and CP_N being normals on the forces Q and P respectively from the point of contact C

Mechanical advantage of $P >$ or $<$ that of Qr according as

$$P \times CP_N > \text{or} < Qr \times CQ_N$$

$$\text{or } \frac{P}{Qr} > \text{or} < \frac{CQ_N}{CP_N} \quad (1)$$

From similarity of triangles

$$\frac{CQ_N}{CP_N} = \frac{AP_N}{AQ_N}$$

1 When the arm hangs by the side and as ω reaches 90° from 60° (ω being the angle between CO and OA) CP_N increases from r to a higher value and $CQ_N = r$ This is equivalent to elevation of the arm to 30° from hanging position

$$\text{or } CP_N > r$$

$$\text{or } CP_N = r + k$$

The mechanical advantage

$$\frac{P}{Qr} = \frac{CQ_N}{CP_N}$$

$$\text{or } \frac{P}{Qr} = \frac{r}{r + k}$$

$$\text{or } \frac{Qr}{P} = 1 + \frac{k}{r}$$

$$\text{when } \omega = 90^\circ \quad k = r$$

$$\text{or } \frac{Qr}{P} = 2$$

$$\text{or } 2P = Qr$$

In the other words P is mechanically advantageous in the initial phase of lifting The action potential at this stage being low P requires reinforcement by Qr

2 As the arm is elevated AP_N tends to diminish up to 90° of elevation thereafter it increases as the arm is further raised In the

vertical position the contact point being near the lesser tuberosity the direction of P becomes almost parallel to the axis of the humerus and passes close to S In this position the angle between P and Qr becomes minimum and is designated as μ In this position CY is CY $\cos\mu = CQY \times \sin(90° - \mu) = CQY$ which evidently cannot be less than r

In the condition where

$$CPY > r \quad YPY < YQY$$

$$\frac{CQY}{CPY} = \frac{YPY}{YQY} < 1$$

for mechanical advantage

$$\frac{P}{Qr} < 1$$

$$\text{or } P < Qr$$

In other words the mechanical advantage of P is more than that of Qr as the elevation nears the vertical position though its action potential falls to minimum The action of the short rotators is essential for steering the head to the vertical in this crucial phase of elevation

3 When the arm is raised to vertical $YPY \rightarrow 0$ Qr passes near the points of contact at this stage Therefore CQY also tends to be 0 In this position mechanical advantage of P is still greater than that of Qr which tends to 0

Similarly the limits of optimum role of the steering muscles (short rotators) prime movers and depressors (intermediate group) can be worked out mathematically using general notations in the plan view In figure 14 the steering muscles in one direction have been termed Qr acting at an angle of β with the line joining C and O prolonged to the point of the action of the resultant on the tuberosity at S in the plan view In other words the limit of range of steering is $+\beta$ and $-\beta$ with the axis on either side The angles are not equal in view of the presence of retrotorsion of the head neck on the shaft axes Let the prime movers (P) similarly bear an angle of $+\alpha$ and $-\alpha$ with the axis of the shaft in the plan view at A The distance between A O and C is d (CO being projected on the axis in the plan view) and similarly the distance between S O and C is d_1 (SC being projected in the plane of the shaft axis in the plan view) The steering couple will be $Qrd_1 \sin(\pm\beta) \pm Pd \sin(\pm\alpha)$

To meet the best result of steering effect *i e* to and from rolling of the head of humerus in the glenoid the forces Qr and P should be synchronous and homodirectional in their pull

β is always greater than α. Qr > P beyond 120° of elevation (from electromyographic study) and therefore

$$\frac{Qr}{P} \cdot \frac{\sin(\pm\beta)}{\sin(\pm\alpha)} > 1 > \frac{d}{d_1}$$

i.e. the steering effect of Qr is more effective than that of P. From above it is seen that P is advantageous in all stages of elevation. Qr is essential

(a) At the initiation of lifting from hanging position of the arm (vide infra).

(b) Beyond 90° of elevation when the pull of deltoid gradually tails off (electromyographic studies).

Indeed the maximum steering effect is required after the shoulder has reached 120° of elevation when Qr starts getting its peak action potential.

To summarise, in the initial stage of lifting the short rotators play the major role up to about 30° of elevation. Between 30° and 120° the lifting is carried out mainly by the prime movers and again from 120° to 180° the steering muscles take a major role in lifting. The steering muscles should be acting as close to the bend of the axis as possible so that the angle $\beta > \alpha$.

MINIMUM REQUIREMENT OF POWER FOR OVERHEAD ELEVATION OF THE SHOULDER. PREREQUISITES AND POSSIBILITIES OF TRANSFER OF POWER IN FLAIL GLENO HUMERAL JOINT

Reserve muscle power of the gleno humeral joint is in abundance. This makes the limb useful in lifting heavy weights, tackling the opponent in wrestling and other heavy duties. All of it is not needed for lifting the shoulder overhead and in performing ordinary daily chores.

The deltoid and the clavicular head of the *pectoralis major* are the

only muscles having no alternative power to replace their function These give motive power for lifting Their insertion is furthest from the joint to enhance mechanical advantage

Of the steering group the infraspinatus has been shown to be a posterior glider of the head of the humerus during the end stages of elevation overhead The action thus is similar to that of subscapularis in this position Retrotorsion of the head of the humerus which changes into relative antetorsion in the overhead position predisposes to anterior subluxation Its prevention requires extra power for backward gliding Infraspinatus gives this power This muscle has got a minor role during backward elevation of the limb though the backward elevation is only possible to about 80° It glides the head of the humerus in this plane

Supraspinatus and subscapularis are arranged in such a manner that they are capable of steering the humeral head during overhead elevation in different planes through an arc of about 150 The extremes (about 30 on either side) of the arc are helped by forward and backward migration and vertical rotation of the scapula These steering muscles also fix the head of the humerus in the glenoid at each instant of elevation Their action follows the general rule that the muscle fibres which fall in the plane of the movement give the vertical gliding of the head of the humerus with the commencement of motion The fibres anterior and posterior to these glide the head in the horizontal plane at a subsequent stage Therefore it is obvious that supraspinatus and subscapularis are indispensable for elevation The minor vertical gliding during elevation backward by infraspinatus does not however take place

The intermediate group of muscles comprising pectoralis major latissimus dorsi and teres major et minor are vertical depressors having a little steering and fixation action These help lifting heavy weights overhead therefore the limb loses some of its effectiveness in lifting heavy weight when these are knocked out

Scapular rotation round an antero posterior axis through its body is the most important of all the girdle movements Fixation of the blade during elevation of the limb is just as important Gravity the lower fibres of serratus anterior and rhomboids have been seen to be sufficient for this Upward and forward migration and the vertical rotation of scapula round the chest wall during elevation is effected indirectly though inefficiently by the muscles moving the gleno humeral joint The remaining girdle muscles though fewer in number may be used for

transference They are whole of the trapezius pectoralis minor upper two digitations of serratus anterior and levator scapulae

The classical methods of transfer of a single muscle or several muscles to a common attachment for abduction power do not consider the role of steering muscles when paralysed and fail to substitute their function in their absence So both on the theoretical consideration and clinical experience we find that the arm cannot be lifted more than 90 and that too with grossly altered scapulo humeral rhythm This corroborates the observations of Merle d Aubigne

The power in absence of delto pectoral complex is given by trapezius Trapezius should be transferred using its full extent of its insertion to replace the anterior and middle fibres of deltoid Wider angle of rerouting by multiple crushing of the acromion and spine helps wider pull While rerouting the muscle may be shifted a little forward or backward in presence of imbalance or where we want internal and external rotation of the arm in absence of a suitable substitute

It is very important to assess the power of the steering muscles e g subscapularis supraspinatus and infraspinatus The function of these muscles and in their absence their restoration is as important as replacement of a prime mover Without their aid the prime mover is helpless as an elevator Muscles whose distal ends can be brought to the region of the tuberosities and their general direction of pull corresponds to that of the muscles they are going to replace are suitable for transfer In the process the nerve and vascular supply should not suffer any damage or pull in the rerouted position of the muscle At least any two of these require replacement

The steering muscles should have their rerouting close to the end of the axis of the head and the neck to give pure form of movement at the gleno humeral joint Axis being bent rerouting distally causes loss of power for gliding the humeral head No wonder all muscles having this function are inserted round the bony tubercles situated at the outer end of the head neck axis

The subscapularis power can be replaced by pectoralis minor or upper two digitations of serratus anterior whose direction of pull corresponds closely to the direction of fibres of subscapularis The rerouting of these muscles is done anteriorly at the site of the insertion of the subscapularis An alternative method of replacement of subscapularis function is to provide a posterior glider by posterior transfer of latissimus dorsi and/or teres major to a point exactly opposite the site of the subscapularis insertion i e the tubercle limiting the greater tubero

Table 4 Possible Power Replacements at the Gleno Humeral Joint at a Glance

Muscle requiring replacement or reinforcement	Action	Choice of muscles for transfer in order of preference
Subscapularis	Posterior glider	I Upper two digitations of serratus anterior II Pectoralis minor III Pectoralis major (whole or part) These muscles act almost in the same direction as that of fibres of subscapularis IV Levator scapulae V *Scalenus anterior* VI Scalenus medius VII Splenius capitis VIII Sterno-cleido mastoid These (4-8) act from above therefore are second class substitutes
Infraspinatus	Posterior glider acting from behind	I Latissimus dorsi II Teres major
Supraspinatus	Superior glider	I Levator scapulae II Sternocleidomastoid III Scalenus anterior IV Scalenus medius V Splenius capitis *All of them act from above* therefore are good substitutes
Deltoid and clavicular head of pectoralis major	Prime mover (lifting)	I Trapezius as far down as possible on the shaft

sity Here the action is from backward though identical with that of the subscapularis after elevation beyond 90 Latissimus dorsi is a suitable muscle owing to its long fibres and mechanical advantage It has been used successfully as a backward glider to prevent anterior recurrent dislocation of the shoulder Besides when transferred for paralytic shoulders depressor action of the latissimus dorsi is not altogether abolished In several of our cases we found this to be the only *muscle available for transfer*

The levator scapulae scalenus anterior and scalenus medius sple nius capitis and sternocleidomastoid are suitable to replace the su

praspinatus Of these the levator scapulae is the first choice owing to its direction and the length of the fibres All have not been tried for want of suitable cases Table 4 shows the possible transfers

The intermediate group of depressors if present after the required transfers are done enhance the power of lifting heavy weights Their absence however does not impair the range of movement of the limb though it diminishes its performance

The lower six digitations of serratus anterior and rhomboids with the help of gravity are adequate to act as the force rotating the body of the scapula round the antero posterior axis In the absence of these we have to fall back upon one of the standard methods (vide introduction) of restoration of power

CRITERIA OF SATISFACTORY RESULT AFTER SURGICAL REHABILITATION

The limb should be capable of elevation through a full arc of 180 in the coronal sagittal or in any intermediate plane Sometimes while the first 60 –90 can be elevated with ease the remaining arc requires help for elevation In these cases there is often premature rotation of the scapula to the point of exhaustion of its full range Further attempt at elevation results in unnecessary bending of the body to the contra lateral side In some cases though the arm can be elevated overhead in the sagittal it cannot be done in the coronal plane owing to the per sistent internal rotation of the shoulder There are cases where the arm can be brought up and held either in the coronal or in sagittal plane by giving a swing to the limb The momentum carries the limb to the desired level where there is enough power to complete elevation and to balance it In others it has been found that while the patient cannot raise the arm overhead with the elbow extended he can do it with the elbow in flexion Obviously it is due to the reduction of the moment by shortening the arm of the lever The critical arc through which the lifting requires the maximum effort is from 60 –120

The scapulo humeral rhythm should be comparable to that of the opposite side during elevation The adjustment in the setting phase of the scapula is different from person to person though clinically they appear to be the same Where initiation of the elevation is difficult owing to lack of power the scapular rotation may help in passing

through this critical phase to a position where the muscle power is just sufficient to lift the arm through the remaining arc. This of course points to the weakness of the steering muscle in the plane of elevation. The inevitable unilateral shrugging is noticeable in these cases, i.e. the point of the shoulder is elevated prematurely.

The shoulder tip must not move excessively upwards or lag during elevation in the coronal plane. The upward elevation is frequently seen when there is imbalance of power between the elevators of the gleno-humeral joint and fixators of the scapula. We frequently found this to happen after muscle transfer and by training they may eventually be corrected. The lag in elevation is also due to imbalance of the effect of gravity on the limb and the elevators of the scapula. These cases require reinforcement of power.

The vertebral border and the upper angle of the scapula should not unduly project while lifting the shoulder. This is due to lack of power of the serratus anterior deficiency in one power arm of the torque which rotates the scapula in the antero-posterior axis. Lack of power in prime movers or short rotators may in some cases demand greater attention of the patient. Accessory muscles contract with the muscles moving the shoulder. There may be bending of the body to the contralateral side. The patient may show undue strain or exertion and there may be tremors and jerks during maintenance of the motion and finally the position may not be sustained. All these are not desirable in a surgically rehabilitated shoulder. He should be able to lift a reasonable amount of weight and carry out normal functions demanded for his well being.

During rehabilitation it has been found that in the initial stages they may not fulfil the criteria of satisfactory results. New functions demanded by the rerouted muscles so long dormant and/or used for other functions may require a good period of training before he accustoms himself. Improvement of power also develops with the passage of time and resistive exercises. Joint stiffness, particularly in the shoulder, may be a factor in the disturbed function of the limb after operation. The case has to be followed day to day and the cause ascertained in the presence of altered functions and treated accordingly.

To summarise, the criteria of satisfactory results after surgical rehabilitation are:

1. The limb should be capable of elevation through the full arc of 180 either in the coronal, sagittal or in any intermediate plane.

2 The scapulo humeral rhythm should for all practical purposes be comparable to that of the healthy side
3 Vertebral border and the upper angle of the scapula must not unduly project while lifting the shoulder
4 The shoulder tip should not move excessively upward or lag in the coronal plane
5 The movement should not be jerky while elevating the shoulder and the patient must not show visible effects of undue exertion
6 He should be able to lift a reasonable amount of weight

CLINICAL AND ELECTRICAL ASSESSMENT OF POWER IN NORMAL AND IN PARALYSED SHOULDER

Periodic clinical assessment of muscle power is necessary to record day to day improvement or deterioration of the strength of individual muscles or muscle groups following a lower motor neurone lesion from any cause It is also essential to know the power of each muscle before planning a reconstructive operation which involves transference of one or more muscles It is frequently seen that the transposed muscle is often at some mechanical disadvantage in its new position and also that the available muscle for substitution is of less bulk and consequently weaker even in the normal state than the muscle which it is going to replace These cases fail to give expected results even in efficient hands Clinical grading of muscle power has to be accurate and standardised Grading according to the Medical Research Council (M R C) scale appears to be quite satisfactory and easily done even in a busy outpatient department The scale is divided into six grades as follows

0 Complete paralysis
1 Muscle responds with slight flicker on volition
2 Can move the part on volition when gravity is eliminated
3 Can move the part only against gravity
4 Can move the part against gravity and some resistance
5 Normal power

Any intermediate value is denoted as + or + + affixed to the basic power As for example if the forearm can be extended against gravity and maintained in that position for any length of time or till any

resistance brings it down then the triceps is graded as 3. But if the patient is able to extend the elbow against gravity only for a brief period and cannot sustain it, in that case the triceps is graded as 2.

The corroborative and supplementary assessment is done with the help of the strength duration curve. During clinical power testing the action of the associated agonist if any and antagonists is eliminated by the positioning of the limb. It is often extremely difficult if not impossible to exclude the group action during a particular movement. This often leads to rather optimistic data and on transfer these muscles are found to lack the power it was expected to replace. The determination of the strength duration curve helps to arrive at a more accurate estimation particularly in connection with the deeper muscles. It helps to assess the state of denervation or innervation of a single muscle.

During clinical assessment it is often necessary to instruct the patient and to explain carefully the exact movements to be performed. Co-operation of the patient is essential. The power of muscles is judged in certain positions while performing a specific movement in a specific direction. This helps isolation of a muscle action which would otherwise be difficult or impossible in the presence of group action. It is frequently necessary for the examiner to fix a particular joint or part of the body to obtain the best mechanical advantage during the performance of the act. Different portions of a large muscle may require special examination in different positions. Minor intelligent adjustment of the position and the site of application of resistance during testing may be necessary when optimum effect cannot be elicited due to paralysis of neighbouring muscles. For instance in the test described for sternal part of pectoralis major the deltoid, serratus anterior, triceps and muscles of wrist and hand are assumed to have normal power. In paralysis of these muscles the test has to be modified. The patient sits with the arm hanging by the side. The examiner passively abducts the shoulder to 40° and resists patient's attempt to bring the arm down to the trunk by counterpressure at the elbow. A brief account of the clinical assessment of the power of the different muscles moving the shoulder joint complex (including the accessory joints) is given below. Particular attention is given to the deepseated muscles whose action is difficult to assess clinically.

Trapezius Upper: Patient sits upright. No fixation is usually necessary. Resistance is applied against the acromion and the posterolateral aspect of head i.e. over the mastoid region and the patient is prevented from approximating the occiput to acromion.

Trapezius Middle Patient lying prone with arm in horizontal abduction and in external rotation tries to lift it up from table while the examiner presses the arm down on the table

Trapezius Lower Patient lies prone with the arm in about 120 abduction extension and full external rotation Pressure is applied on the forearm towards the table while patient tries to lift the arm from it If the posterior deltoid and triceps are weak the examiner exerts pressure against acromion while the arm hangs from the edge of the table

Deltoid Anterior Lying supine with the arm internally rotated and abducted (30 -40) elbow flexed hand resting on the chest the patient flexes the arm against resistance at the elbow in the opposite direction

Deltoid Middle Patient sitting or lying on the side with elbow flexed to 90 shoulder abducted to 45 further abducts in the scapular plane against counterpressure at the elbow

Deltoid Posterior Patient lying prone with the arm in 45 abduction and in slight external rotation and extension attempts further abduction and extension against counter resistance at the elbow No fixation is necessary in this manoeuvre

Supraspinatus The supraspinatus muscle lies under cover of trapezius careful palpation and comparison of its bulk in the state of contraction with the normal side is necessary It acts jointly with the middle deltoid therefore it is difficult to assess its power separately

Patient sitting up with the arm by the side in neutral rotation and the head bent towards the same side to relax upper trapezius tries to abduct the arm while the examiner resists this with one hand at the lower end of the arm and palpates with the other the region of the supraspinatus muscle

Infraspinatus and Teres Minor Patient lying supine with elbow flexed to right angle and shoulder in slight abduction and neutral rotation rotates the arm externally against resistance on the radial side of the forearm the arm being fixed at the elbow by the other hand of the examiner

Teres Major Lying supine patient s arm is abducted to 60 and is supported by one hand of the examiner The examiner opposes internal rotation with the other hand on the inner surface of the forearm flexed to 90

Levator Scapulae Patient either lies prone or sits up with elbow flexed shoulder extended and adducted in neutral rotation Fixation of



Figure 15



Figure 16

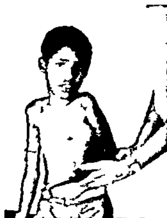


Figure 17

Figures 15–17 The figures show the effect of internal rotation against resistance with loss of subscapularis power and presence of residual power in some of the intermediate group of muscles e g pectoralis major latissimus dorsi teres major and teres minor In the first figure the shoulder dislocates posteriorly when internal rotation is attempted against resistance owing to the presence of pectoralis major The second figure shows anterior dislocation when internal rotation is attempted against resistance in presence of latissimus dorsi The third figure shows minor anterior subluxation in presence of some power (2) in subscapularis

acromion in the normal shoulder level is done by the examiner The patient tries to push the point of the elbow medially and backwards while the examiner opposes with the other hand

If the shoulder muscles are weak the patient is instructed to adduct and elevate the scapula while drawing the inferior angle medially the examiner opposes this movement by attempting to draw the inferior angle outwards

Rhomboids The patient lies prone or sits up with elbow flexed and tries to appose the inferior angle of both scapulae as much as possible against resistance over both the acromions in the forward direction or over the point of the elbow when the posterior deltoid and shoulder fixators are normal

Alternative test (Brunnstrom) The patient lying prone relaxes the trapezius by hyperextension at the shoulder and by placing the hand across the back with elbow at right angle The examiner inserts a finger beneath the vertebral border of scapula and the patient is asked to raise the forearm and hand slightly away from the body when the contraction of the rhomboids can be felt

Subscapularis Patient lies supine with arm abducted to about 120

and externally rotated Examiner fixes the elbow with one hand while he resists internal rotation with the other placed on the medial side of forearm bent to 90

In some cases of flail shoulder with loss of power of subscapularis there is often residual power in one or more of the muscles *e g* pectoralis major latissimus dorsi teres major and teres minor In these cases the shoulder is seen to subluxate further forward or backward when attempting internal rotation against resistance It is due to unopposed pull on the shaft of the humerus by the dominating muscle and want of balance due to paralysed subscapularis which fixes the head in the glenoid (Saha & Banerjee Figures 15–17)

Latissimus dorsi Patient lies prone with shoulder partly abducted (45) extended and arm internally rotated and tries to adduct against the resistance of the examiner s hand on the lower arm or forearm Fixation is not necessary in this position

Serratus anterior (upper two digitations—Saha & Banerjee) Besides its action as a stabiliser with the help of levator scapulae in the setting phase of the scapula during the elevation upper two digitations of serratus anterior bring the scapula forward aided by pectoralis minor in the erect position On lying it is also a depressor of the scapula and helps to rotate the scapula in the clockwise direction on the right side when seen from behind

Patient lies prone and his point of the shoulder and limb are allowed to hang over the edge of the table to minimise the action of the pectoralis minor He pushes the point of the shoulder further forward against resistance applied in front of the shoulder in the neighbourhood of the coracoid process in the opposite direction

Serratus Anterior (Lower six digitations) Standing in front of a wall the patient pushes the wall with both hands keeping both elbows straight and arms in horizontal flexion Any comparative weakness is easily detected by winging of scapula or prominence of its inner border

Serratus anterior is also tested in the supine position The patient pushes the arm perpendicularly upwards while the examiner resists the fist of the patient with the elbow in extension trying to push towards the table When the triceps and deltoid are weak the arm is placed in 90 –120 abduction and in external rotation the examiner places a hand on the point of the shoulder to resist the forward thrust

Pectoralis Major (Sternal part) Patient lying supine holds the upper limb in 90 flexion with the elbow extended and tries to bring the hand down towards the opposite iliac crest The examiner resists



Figure 15



Figure 16



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Subscapularis Patient lies supine with arm abducted to about 120

the movement by one hand against the volar aspect of the forearm and the other on the opposite iliac crest to fix the pelvis

Pectoralis Major (Clavicular part) Patient lies supine with the upper limb in 90 flexion and the arm in slight internal rotation The examiner fixes the opposite shoulder with one hand while he applies pressure with the other hand against the volar surface of the forearm to resist the arm being brought across the chest towards the opposite shoulder

Pectoralis Minor Patient lying supine with hand by the side tries to thrust the point of the shoulder forward and downward without any pressure of the hand on the table while the examiner tries to press the shoulder backwards towards the table

A modified muscle testing chart is used for recording the results of the clinical power assessment Repeated examinations are done in doubtful cases (Table 5)

Strength Duration Curves

Strength duration curves were done in most of the cases This was done to eliminate doubt in such patients who did not co operate properly to elicit contraction of a particular muscle Sometimes it was necessary to assess the contractility in cases of overstretched muscles and also in cases of partially denervated muscles In some cases due to trick movements it was difficult to assess individual muscle action when strength duration curves were plotted to eliminate doubt To assess the ratio of denervated to innervated fibres in a muscle after residual lower motor neurone type paralysis strength duration curve plotting was done From the gradient of the curves it was possible to ascertain the amount of denervation and also to evaluate the muscle power The clinical power assessment was thus further corroborated by plotting the strength duration curves

The constant voltage type of apparatus was used with a range of 0–200 volts It was used because it was well *tolerated even by children* The pulse time bases in this machine were as follows 300 100 30 10 3 1 0 3 0 1 0 03 0 01 m sec

The part to be examined was cleansed with soap and water and a preliminary heating with an infra red lamp kept at a distance of 3 ft for 10 minutes was done prior to the examination

Deep seated muscles *i e* the muscles which are covered by another superficial muscle *e g* supraspinatus rhomboids etc often presented

difficulties in the plotting of strength duration curves In such cases contraction of the whole muscle bulk was observed by a slightly stronger stimulation on the motor point The volume and outline of the muscle in contracted state were compared with that of the normal side For stimulation of subscapularis and serratus anterior the arm was kept fully abducted and externally rotated to obtain an easy approach

POST-POLIOMYELITIC DISTRIBUTION OF PARALYSIS OF THE SHOULDER SELECTION OF CLINICAL MATERIAL FOR A PARTICULAR TYPE OR GROUP OF OPERATIONS

In considering surgical rehabilitation of the paralysed shoulder the residual function is assumed to be retained in the elbow joint and hand If and when their function is impaired there should be possibility of restoration by one or more of the recognised procedures Without their useful function the limb is useless even when the shoulder is rehabilitated The residual stage of the disease begins approximately 30 months after the onset of illness treated by a well planned rehabilitation programme and continues for the remainder of the patient s life During this period surgery renders its greatest contribution to the welfare of the patient though there is a definite place for physical therapy occupational therapy vocational guidance and social services in his eventual rehabilitation after surgery During this stage of the disease when conservative treatment has failed two methods of surgical treatment *e g* arthrodesis of the gleno humeral joint and power transfer are practised and if successful these restore the function of the paralysed limb to a certain degree Each of these methods has its advantages and disadvantages

For an arthrodesis to be successful the axio clavicule-scapular group of muscles must have excellent power Nay the power should exceed that in the normal multi jointed member owing to the increased length and consequent mechanical disadvantage due to the extended leverage No doubt in favourable circumstances it gives strength and power to the limb s performance at the expense of mobility Elevation is usually restricted to 90 120 and many useful movements like putting the

hand in the pocket to back of the head to the opposite side of the body etc cannot be performed gracefully There is a greater likelihood of fracture in falling or when an abnormal strain is put on the already atrophied bone Scoliosis may be produced or exaggerated by arthrodesis In bilateral paralysis arthrodesis would be rather cumbersome and leave the patient more amenable to injury Movable shoulder joint with greater range of motion will be preferable in cases in which it will be necessary to ankylose the elbow joint When there is associated paralysis of the other extremity that precludes the possibility of hard work a movable joint is preferred to a stiff joint In females for cosmetic reasons a muscle transference operation is advisable rather than arthrodesis In the latter the arm projects from the side Under 12 years of age an arthrodesis may not be successful while a transplanted muscle operation may give good results A frequent cause of failure of arthrodesis is the loss of contact between the head of humerus and glenoid due to difficulty in immobilising the shoulder in plaster spica Another cause of failure in children is the predominance of cartilage and lack of good solid bone in the components of the shoulder joint Arthrodesis in children may affect the growth of the humerus

Thus the pre requisite of shoulder arthrodesis *i e* the presence of strong residual power is the axio claviculo scapular group of muscles tends to frustrate the aims for which the arthrodesis is done If some of the power of the girdle muscles could be spared as they can be in the majority of the cases there is a greater chance of having a mobile shoulder capable of greater and more useful performance (*vide infra*)

We have followed the results of Mayer s trapezius transfer prolonged to the insertion of the deltoid combined with stabilisation of the gleno humeral joint by Nicola s procedure We had tried the Bateman procedure combined with the tenodesis in some cases In neither of these the results came up even to the expected minimum especially if the short rotators were weak or completely paralysed

Analysis of 103 consecutive cases of residual paralysis of the upper limb and some with bilateral affection from the B C Roy Polio Clinic are tabulated below (Table 6) The muscles having power less than 3 (M R C) are considered unsuitable for transfer and are tabulated in percentage of the total number These cases had also varying degrees of paralysis of the elbow wrist fingers and thumb The observations tabulated in muscle charts covering a period of more than 7 years do not conform to the tabulation now practised in the clinic Nevertheless the data give a sufficient indication of the type of muscle that is most

affected in this country. From this group we have excluded all cases that could lift the shoulder overhead even in the absence of deltoid power.

Table 6

Muscle	Number affected power below 3	Percentage of total of 103 cases
Deltoid (total paralysis)	61	59.2
Deltoid with some *residual active fibres*	42	40.7
Spinati	64	62.1
Rhomboids	24	23.3
Trapezius	12	11.7
Serratus anterior	12	11.7
Teres major	46	44.7
Latissimus dorsi	46	44.7
Levator scapulae	16	15.5
Pectoralis major	49	47.6

The muscles having power less than 3 were given pre-operative physiotherapy and exercise to improve their function. It is curious to note that paralysis affecting the upper extremity may be mostly in connection with the activity imposed on the limb during the period of incubation and the early phase of manifestation of the disease. *There*fore it was found mostly on the right side in right handed persons.

Less frequently affected muscles are the ones we have chosen for transfer in various combinations to restore power. These muscles are trapezius, levator scapulae, sternocleidomastoid, latissimus dorsi, teres major, upper two digitations of serratus anterior and pectoralis minor.

Further close studies of the series enabled us to sub-divide the cases into the following five groups.

1. In this group, fortunately extremely rare in our country, the girdle muscles are badly affected, particularly the serratus anterior, levator scapulae, rhomboids and trapezius, in addition to the deltoid and short rotators of the gleno-humeral joint. The rest of the muscles of the limb are in good shape. Over a period of about two and half years we have not been able to find a single case of this nature.

2 The second group presents a minor affection of a portion of the deltoid the posterior fibres generally retaining power with varying degrees of weakness of the short rotators and practically normal power in the rest of the limb including the shoulder girdle There is a gross flattening of the shoulder and sometimes a subluxation is present In some cases the patient retains the ability to raise the limb vertically with assistance The most crucial stage where he needs assistance is 60 120 abduction

3 There is complete paralysis of the deltoid supraspinatus infraspinatus with paresis of teres minor et major subscapularis biceps brachialis and supinator of the forearm Otherwise the hand forearm and elbow have for all practical purposes fairly good power If at all the girdle muscles in this group are affected to a very minor extent There is forward and downward subluxation of the limb at the shoulder and on attempted movement it is exaggerated

4 In this group there is complete paralysis of the abductors the short rotators of the arm pectoralis major latissimus dorsi with a slight weakness of the trapezius elevators of the shoulder blade and serratus anterior In this group we very often find that the elbow is flail the forearm long flexors and extensors affected to a great extent and intrinsic muscles particularly of the thenar eminence occasionally paralysed The limb is subluxated to a greater degree than in the preceding group and the subluxation does not change very much on attempt to move the limb at the shoulder

5 In the last group complete paralysis is found in the abductors short rotators pectoral group of muscles latissimus dorsi flexors and extensors of the elbow pronators and supinators of the forearm and greater involvement of the long flexors and extensors and the intrinsics and may be only one or two tendons of long extensors and/or flexors are left The whole extremity is useless to serve any function This group has been found to have a fair amount of residual power in serratus anterior levator rhomboids and trapezius Sternomastoid scalenus anterior scalenus medius and splenius capitis in all these groups have not been found to be affected Such limb is very often a useless load to the patient and he himself often asks for its removal These cases have often scoliosis with a primary curve on the side of the paralysed limb

Selection from amongst these cases for a particular type of operation is dependent on very careful assessment of power of the functioning muscles and the paralysed group In our experience we did not find two cases exactly similar Decision is to be taken as to the possibility of the elbow and hand rehabilitation so that the patient is able to carry out at least the bare minimum that is expected of him for his well being

In the first two groups the standard operations that are practised can be chosen to rehabilitate the shoulder Reinforcement of the force couple rotating the scapula multiple muscle transfer of Harmon Ober s transplant or Bateman s procedure may be adopted

In the last three groups one or more of the methods outlined in this monograph should be undertaken to rehabilitate the shoulder movements It is curious to note that the muscles which are multisegmental in origin tend to retain some power Such muscles are trapezius serratus anterior and the pectoral group How the rhomboids and levator scapulae are spared in most of the cases though they have supply mainly from a single segment is not known

In some of the present cases where according to the previous knowledge of surgery muscle transfer operations could not be attempted nor arthrodesis done owing to weak girdle musculature there is now hope of restoring power on the basis of the new concepts of the shoulder mechanism and rehabilitation Till recently these cases had to be satisfied with a flail shoulder with possible surgical restoration of the fingers and hand or in case this was not possible they had to be amputated

The importance of these procedures should not be considered lightly From the socio economic point of view crippling conditions of child hood are a burden not only to one s family but also to society The gradually extending scope of surgery may make some positive social contribution by enabling patients with residual paralysis to earn a livelihood by undertaking some sort of work

SURGICAL PROCEDURES FOR REHABILITATION OF FLAIL SHOULDER

Either two or more of the procedures described below were used in the rehabilitation of the flail shoulder Power in all the cases operated was zero for deltoid with loss of power of one or all of the short rotators of the upper end of the humerus The power of latissimus dorsi pectoralis

major et minor teres minor et major in many cases was zero eith singly or in all Trapezius latissimus dorsi (when present) levat scapulae pectoralis minor (when present) upper two digitations serratus anterior and sternocleidomastoid were transferred to gr elevator and short rotator power in various combinations

The sabre cut incision has proved to be suitable for all types transfer Supplementary incisions may be used in the floor of tl axilla near the posterior axillary fold for the dissection of latissimi dorsi and for the delivery of the upper two digitations of serrati anterior detached from the vertebral border of scapula before reroutir to the lesser tuberosity In all the procedures where trapezius requir rerouting the deltoid is severed along the whole length of its orig except for a few posterior fibres Its power being zero in all the case the cut edge is not resutured The bundling due to gravity of tl severed deltoid helps give a round contour of the flat shoulder It al facilitates delivery of the head of the humerus with the tuberositi and the upper two to three inches of the shaft in the wound The sit where rerouting is done are made raw either by the formation of periosteo aponeurotic pocket or erasion of the periosteum

The patient should be placed on the sound side and fixed with roll bandages in such a way that the tip of the affected shoulder can l tilted 30 forward or backward during the operation

There is a considerable amount of haemorrhage from the sabre c incision from the cut edge of the deltoid the tissue beneath the acr mion and the outer end of the clavicle This is minimised by a liber infiltration with one in 500 000 adrenaline hydrochloride in norm saline and use of diathermy The skin incision however should not l made with a diathermy knife In our experience it delays healing ar leads to hypertrophied scars and keloid this being a particularly f vourite site

Glucose saline transfusion is required in all the cases during tl prolonged procedure The suture material used in all cases was sil from size number 2 to 4

1 *Modified Procedure of Trapezius Transfer as Advocated by Bateman*

It is known that the longer the muscle fibres the greater the shorter ing and therefore the greater the excursion of the segment whe such a muscle is transferred Besides the greater the distance from th

joint of the rerouted muscle the better its mechanical advantage While transferring the trapezius for deltoid power Mayer extended the site of rerouting of the muscle sandwiched between the two leaves of fascia lata The principle is sound though the fascia lata ultimately stretches with loss of considerable amount of lifting power Bateman modified the procedure by transferring the whole of the acromion process with the trapezius to the neighbourhood of the tuberosity of the upper end of the humerus Here again the leverage is too short and therefore there is a waste of available power

It has been found that the upper and middle trapezius can be mobilised from its insertion throughout its length This mobilisation does not affect the blood or nerve supply and gives an extra length of over two inches permitting rerouting on the shaft well below the tuberosities

The classical vertical incision does not facilitate this extensive mobilisation of the trapezius The sabre cut incision has been found most suitable It is given with convexity inwards starting from a point a little above the lower border of the anterior axillary fold at about its middle to a little below the base of the spine 1 lateral and parallel to the vertebral border of the scapulae Flaps are dissected to expose the trapezius to 1 beyond the vertebral border of the scapula where it turns round the base of the spine to be attached to the spinous process acromion process capsule of the acromio clavicular joint and the outer ⅓ of the clavicle The fibrous paralysed deltoid is exposed throughout its origin and the distal flap is dissected so that the head neck and upper part of the shaft of the humerus may be brought through the incision Further infiltration of the solution (adrenaline saline) is given along the origin of deltoid which is subsequently severed by diathermy The head neck and shaft of the humerus is now free to be dislocated above the severed deltoid The anterior border of the trapezius is defined at its insertion to the clavicle The conoid ligament is identified and the clavicle cut through immediately distal to this ligament The scapular notch is felt and the acromion process with an adjoining portion of the spine of the scapula is defined the spine is severed bevelling posteriorly with Gigli s saw The detached portion of the trapezius with the distal end of the clavicle capsule of the acromio clavicular joint acromion process and the adjoining portion of the posterior border of the spine is raised and further mobilised along its posterior border with the help of a rougine from the upper border of the remaining portion of the spine to its base where the lower fibres

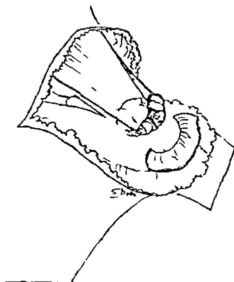


Figure 18

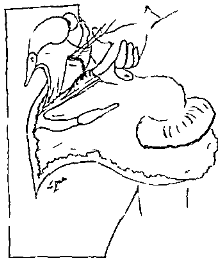


Figure 19

Figure 18 The figure shows trapezius rerouted to the upper end of the shaft of the humerus below the tuberosities. Multiple crushing of the acromion helps coaptation with the curve of the shaft of the humerus. Levator scapulae is seen transferred to lesser tuberosity.

Figure 19 The figure shows reflected deltoid, trapezius and levator scapulae as seen from behind through a sabre cut incision. The levator scapulae is doubled on itself and fixed with loose transfixation silk suture. Index finger is passed behind the upper part of serratus anterior and hooks the first two digitations of the muscle with its attachment still at the vertebral border of the scapula.

glide over the triangular area. The muscle is raised from its bed for rerouting after freeing the remaining part of the anterior border from the investing layer of deep cervical fascia.

The lower surface of the divided portion of the clavicle, acromion process and the adjoining spine is denuded of all soft tissues and periosteum to expose the raw bone. The bones thus exposed are broken with bone forceps at several sites but continuity of the periosteum is maintained to facilitate its taking the contour of the shaft of the humerus at the site of fixation (Figure 18). The site of rerouting on the humerus is also denuded of periosteum where the acromion with trapezius is fixed with two screws. The muscle is to be kept in maximum relaxation to ensure adequate lowering of the site of the rerouting. This is done by adjusting the limb in the zero position or thereabout

The rerouting may require a little forward and backward shifting depending on the lack of suitable replacement of the external or internal rotators The forward shifting will restore the external rotation and the backward shifting the internal rotation of the arm

Fixation with the screws is done last with other muscles when these are to be transferred so that there is very little adjustment of the arm required during the rest of the operation

The limb is plastered in the zero position with special care to ensure positioning of the arm in the scapular plane

2 Transfer of the Upper Two Digitations of Serratus Anterior to Replace or Reinforce Subscapularis as a Glider Towards the Second Half of Abduction (90 –180)

The patient is placed on the sound side and fixed so as to be able to be tilted 30 backward or forward Liberal infiltration with 1 500 000 solution of adrenaline in normal saline is done in the line of the incision and over the spine of the scapula acromion and the outer end of the clavicle

After mobilisation of the trapezius through a sabre cut incision as described earlier for its transfer it is further reflected upward and backward to expose the upper part of the vertebral border of the scapula and the levator scapulae at its insertion After defining the lower and upper borders of the levator scapulae near its insertion the muscle is erased from the dorsal upper third of the vertebral margin of the scapula with the periosteum taking care of the nerves to rhomboids and vessels lying deep and more medially The muscle may be used for fixation as an elevator fixator and a glider when and where necessary By raising the vertebral border of the scapula in its upper part the upper two digitations of the serratus are defined at its upper border hooking it with a blunt instrument or index finger introduced near the upper angle of the scapula between the serratus anterior and subscapularis (Figure 19) The insertion is erased throughout the upper part of the vertebral border to the level of the base of the spine with the help of a rougine working from the cut edge of the periosteum left after detachment of levator scapulae This insertion merges with medial limit of the origin of the subscapularis which is left undisturbed The junction between the erased serratus anterior and subscapularis has to be divided with a scalpel keeping its edge more towards the subscapularis The freed upper two digitations can now be

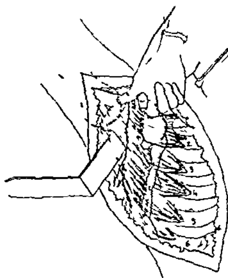


Figure 20

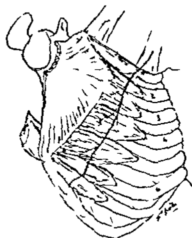


Figure 21

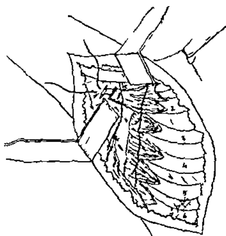


Figure 22

Figure 20 The figure shows the upper two digitations of serratus anterior exp o and held by the index finger through an axillary incision close to the posterior w The subscapular vessels are seen tied and divided between ligatures

Figure 21 The figure diagramatically represents the origin and insertion serratus anterior with its nerve supply Being close to the origin of the upper digitations the nerve is free from danger

Figure 22 The figure shows rerouting of the serratus anterior folded on itself three interrupted sutures to a periosteo aponeurotic pocket over the lesser berosity Transfixation sutures are seen drawn through the pocket before lighten The neurovascular bundle is seen retracted upwards and laterally

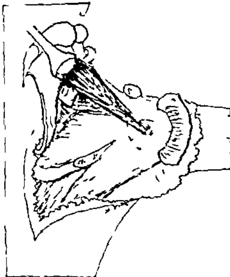


Figure 23

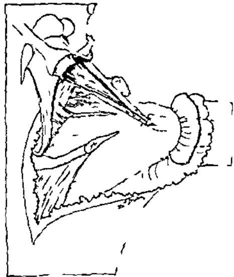


Figure 24

Figure 23 and 24. The figures show further dissection of levator scapulae to enable it to be drawn to the tuberosities of the humerus. It may be rerouted to the greater tuberosity to replace supraspinatus. It may also be rerouted to the lesser tuberosity when there is no other muscle available to take over the function of subscapularis.

folded on itself by three interrupted sutures and transfixed by long stout (No. 3) silk for rerouting. Section of the denuded upper medial angle of the scapula and its adequate retraction help the above procedure. The limb is elevated to about 130° and axilla is incised in its floor close to its posterior wall taking care of the subscapularis vessels which often require ligation and the thoracodorsal nerve in case the latissimus dorsi has residual power. Retraction of the neurovascular bundle upward and laterally helps the finger to be pushed above the upper border of the serratus anterior to the 1st rib (Figure 20). The nerve to the serratus anterior being near its origin in this region is not liable to injury (Figure 21). The transfixed silk thread with upper two digitations is pulled out anteriorly to the axilla. Rerouting on the lesser tuberosity is done in the usual way exposing it behind the neurovascular bundle by blunt dissection (Figure 22).

3. *Transfer of Levator Scapulae as a Short Rotator, Fixator and Glider*

Owing to its long fibres the levator scapulae may be given a choice of rerouting depending on the deficit of power. The exposure and detach

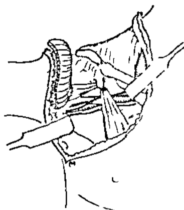


Figure 25

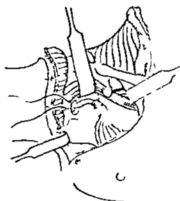


Figure 26

Figure 25 The figure shows exposure of pectoralis minor with its insertion to the coracoid process through a sabre-cut incision as seen from the front In all the cases where this muscle was used the pectoralis major muscle power was 0 and therefore there was no difficulty in the dissection of pectoralis minor The nerve to the muscle is more medial and is not visible during the operation

Figure 26 The figure shows pectoralis minor being drawn through a pocket on the lesser tuberosity behind the neurovascular bundle which is retracted laterally and upwards

ment of the insertion from the vertebral border of scapula has been described (*vide supra*) Only the upper skin flap has to be dissected a little more to expose the belly to about its middle so that it can be drawn either to the greater or lesser tuberosity The method of re routing is the same as that of serratus anterior (Figure 34 and 24)

4 *Transfer of Pectoralis Minor to Replace Subscapularis*

This muscle can be transferred in those cases where the pectoralis ma jor has lost its power and there is no alternative muscle to take over the gliding function of the subscapularis *i e* latissimus dorsi or the upper fibres of the serratus anterior This is a fairly strong muscle and has long fibres Its insertion is aponeurotic which helps rerouting The sabre cut incision is used over the shoulder as described above The insertion of the pectoralis minor to coracoid process is exposed (Figure 25) Its nerve supply being more medial there is no chance of any injury to it The tendon is erased from the coracoid process and a No 3 silk mattress suture is applied with loose ends (Figure 26) The

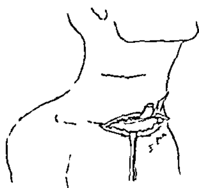


Figure 27

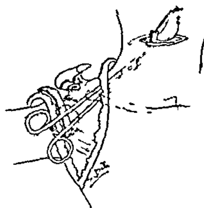


Figure 28

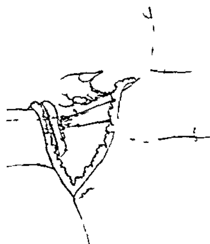


Figure 29

Figure 27 The figure shows the severed origin of sternocleidomastoid. Second crease incision is seen.

Figure 28 The figure shows sternocleidomastoid delivered through second incision before being drawn through subcutaneous tunnel. Sabre type incision with severed deltoid is shown. Trapezius with acromion and clavicle is also visible.

Figure 29 The figure shows the muscle rerouted to the greater tuberosity to replace the supraspinatus.

arm is abducted and externally rotated bringing into prominence the lesser tuberosity below the retracted neurovascular bundle. A periosteo aponeurotic pocket is made over the lesser tuberosity and rerouting is done in the usual way.

Transfer of Sternocleidomastoid to Act as an Elevator

Sternocleidomastoid has been used as a flexor of the elbow with good results. It was felt that it could as well be used as an elevator of the shoulder, the only drawback being that on contraction it may produce

a web in the neck A curved incision is given from the middle line to the junction of the medial fourth and the outer three fourths of the homolateral clavicle The two heads of origin are isolated from the sternum and clavicle and severed (Figure 27) The muscle is raised from the deep cervical fascia to about its lower third retracting the upper skin flap Transfixation suture is applied after narrowing the two origins by interrupted silk sutures A second incision is given in the neck fold at about the middle of the sternocleidomastoid The muscle is freed from above and below without injuring the vessels and the nerves supplying it which come from above The muscle is withdrawn to the second incision and brought subcutaneously through the sabre cut to be fixed to the greater tuberosity (Figures 28 and 29)

6 *Transfer of Latissimus Dorsi and/or Teres Major to Take over the Function of Subscapularis (Posterior Glider)*

The patient lies with 70° tilt on the sound side The arm is controlled by an assistant and is elevated to 135 –140 An incision is given in posterior axillary fold extending from a point about 2½ –3 below the crease of the axilla in the upper arm to the inferior angle of the scapula crossing the crease in a zigzag fashion The insertion of the latissimus dorsi is exposed and severed The muscle is raised from its bed taking care of its nerve and blood supply Retraction of the neurovascular bundle with coracobrachialis helps the dissection when isolated transfer of latissimus dorsi is needed and its tendon has to be freed from the teres major below If it has to be reinforced by teres major then both these structures have to be dissected free from the surrounding tissues The tendon is blended with teres major close to the insertion

The tendon or the tendon and muscle is folded on itself to reduce the width by three interrupted silk (No 2) sutures The reduced tendon is transfixed with stouter silk (No 3 or 4) by a mattress suture with long loose ends (Figure 30)

The interval between the deltoid and triceps (long head) is dissected with a blunt instrument The finger is insinuated to palpate the tubercle at the posterior lower limit of greater tuberosity of the humerus This when the deltoid is severed from the acromion in complete paralysis can be located by inspection (Figure 31)

The tendon of the latissimus dorsi is now free to be taken through this interval to the tubercle just mentioned and fixed by mattress sutures holding the limb in the zero position (Figure 32)

Figure 30 The figure shows latissimus dorsi severed from its insertion and folded upon itself by interrupted sutures A long stout mattress suture fixing the tendon is seen being passed through the second incision on the deltoid ready to be pulled deep to the muscle (Saha A K Theory of Shoulder Mechanism—Descriptive and Applied Springfield Ill Charles C Thomas Publisher 1961 Reproduced by courtesy of the Publisher)

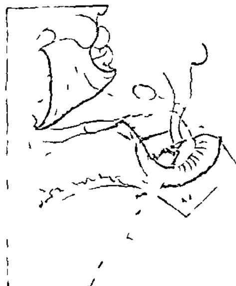


Figure 31 The figure shows a transverse periosteoaponeurotic pocket on the shaft below the insertion of infraspinatus which is located by palpation after reflection of the paralysed deltoid The latissimus dorsi is seen drawn through this pocket for rerouting

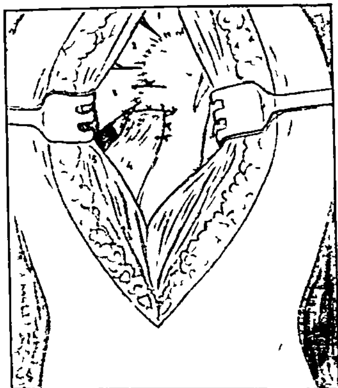


Figure 32 The figure shows the alternative method of rerouting latissimus dorsi through a vertical incision splitting the deltoid to expose the region (Saha A K Theory of Shoulder Mechanism—Descriptive and Applied Springfield Ill Charles C Thomas Publisher 1961 Reproduced by courtesy of the Publisher)

Any other transfer to be done is completed through the sabre cut incision before the limb is finally plastered

POST OPERATIVE MANAGEMENT

After the operation the limb is put in a thoraco brachial spica with shoulder abducted to about 135 in neutral rotation and flexed in the plane of the scapula This plastering becomes easier if it is done by the two stage procedure In the first stage a jacket for the trunk is applied with a crossbar over the opposite shoulder to prevent the jacket falling downward In the second stage after the operation the spica is completed in the position above mentioned

After the removal of the skin sutures on the 10th post operative day

the limb is plastered in the same position and the patient is discharged after a check radiograph to prevent the possible downward subluxation of the joint which may otherwise be a serious complication

The plaster is finally removed after 6-8 weeks when there is a bony union between transferred acromion process and the humerus The limb is rehabilitated for functional recovery

Swinging the limb with the trunk bent forward is the best form of rehabilitation exercise In the course of a week the shoulder gets free to move in any direction Exercises in the lying down position and crawling against the wall help develop the scapulo humeral rhythm Later the patient starts lifting small weights while lying on the bed from side and front This helps develop power and co ordination

In some cases if pain persists the patient requires infiltration with hydrocortisone in the periarticular structures around the greater tuberosity of the humerus

COMPLICATIONS

In our series of cases we did not require any blood transfusion even when the operation continued for 3 hours or more

Sepsis is avoided by scrupulous adherence to routine and by sealing the incisions with a little antibiotic cream and sticking plaster before the limb is put in plaster

Inferior subluxation below the glenoid cavity happened in two cases This should be forestalled and the position adjusted before the limb is put in the final plaster (Figure 33)

Detachment of the acromion from the new site of implantation occurred in three of our cases with the loosening of the screws (Figure 34) They required reimplantation at a subsequent date This is prevented by adequate roughening of the contiguous surfaces of the acromion and humerus and fixation with the help of at least 2 screws The muscle should be relaxed by adequate elevation during the period of immobilisation The removal of plaster should not be done till union is complete between the acromion and the humerus In one case the serratus anterior (upper two digitations) sutured to the lesser tuberosity of the humerus snapped with bundling of the muscle in the axilla after nine days of the commencement of rehabilitation The patient suddenly lost the power of overhead elevation which she had gained in this short period She could however raise the shoulder to about 90 with disturbed scapulo humeral rhythm





Figure 33 *Figure 34*

Figure 33 The figure shows subglenoid dislocation of the head of the humerus as a postoperative complication

Figure 34 The figure shows detachment of the rerouted trapezius due to faulty union with the shaft of the humerus Only one screw was used for fixation which added to the mishap

Inadequacy of power is the result of faulty selection of the muscle transposed for a specific purpose This is avoided by a careful analysis of the residual power and potentialities of the usefulness of the limb when these muscles are transferred The limb should be studied as a whole and not for a specific joint movement Even in case of inadequacy power can be improved by resistive exercises once the muscles transferred are correctly chosen

The scars around the shoulder may hypertrophy or form keloid this being a favourite site We had a few of these The axillary incision should be given in a zigzag fashion to prevent scar contracture Treatment when keloid and hypertrophied scars formed was local infiltration with xylocaine 1 per cent solution with hylase and hydrocortisone acetate suspension In most cases it cleared after two or three weekly injections

Web formation by the transferred sternocleidomastoid may be prevented by taking the muscle beneath the investing layer of deep cervical fascia instead of subcutaneously This also improves the mechanical advantage

ILLUSTRATIONS FROM CASE RECORDS WITH RESULTS

In our experience no two cases were exactly similar. Each case presented a problem of its own. Therefore it is felt that the purpose of this monograph would be better served if illustrative cases are presented with their final follow up. For reasons mentioned in the preface the overall statistics with comparative evaluation of older methods has been withheld. Besides, the various combinations of the operations done for flail shoulder would be numerous and in any case would not help tabulation with so variable residual power distribution in each case of our limited series.

The transfer of muscles, *e.g.*, scalenus anterior, scalenus medius, splenius capitis and part or whole of pectoralis major for short rotators have not been done in any of our cases though their possible use has been mentioned in the text.

Case No. 1

K. C. B. Male 7 years had acute attack of poliomyelitis at the age of 3 years. He was admitted with weakness of the right upper limb and inability to lift the shoulder. His right elbow, wrist and finger though less powerful than those on the left was capable of carrying out function not requiring great strength. The residual power distribution in the right shoulder joint complex was

Deltoid		Latissimus dorsi	4+
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	5
		lower six digitations	5
Short rotators			
subscapularis	3+	Rhomboideus major	4
supraspinatus	0		
infraspinatus	3	Rhomboideus minor	4
Pectoralis major	4	Levator scapulae	4
Pectoralis minor	2	Teres major	0
Trapezius		Teres minor	2
upper	5		
middle	5	Sternocleidomastoid	5
lower	5		

The right shoulder joint was subluxated anteriorly and downwards.

On review of the power chart it appeared that the conventional trapezius transfer should be adequate to lift the arm overhead. Of the short rotators subscapularis and infraspinatus had a fair degree of power though not adequate to



Figure 35 The figure shows ability to lift the right arm overhead He had trapezius and latissimus dorsi transfer

prevent anterior subluxation Therefore latissimus dorsi transfer to act as posterior glider was considered necessary He was operated upon under general anaesthesia trapezius being transferred for deltoid power and latissimus dorsi to act as posterior glider Plaster was removed after 6 weeks for rehabilitation (Figure 35)

This case had no supraspinatus power The supraspinatus was neither replaced by a transfer though available Elevation in the scapular plane requires action of supraspinatus It is possibly helped by power transmission of the adjoining fibres of the subscapularis and infraspinatus through the rotator cuff The latissimus dorsi has reinforced the power of subscapularis in the terminal phase of elevation The presence of pectoralis major has added to the efficiency of the limb

Case No 2

M K Female 14 years was admitted with snapped trapezius and infraglenoid dislocation of the head of the humerus She had Bateman procedure done with a classical longitudinal incision for flail right shoulder Her power in the right shoulder joint complex was as follows

Deltoid		Latissimus dorsi	4++
anterior	1		
middle	0	Serratus anterior	
posterior	1	upper two digitations	5
		lower six digitations	5
Short rotators			
subscapularis	2	Rhomboideus major	3++
supraspinatus	1		
infraspinatus	1	Rhomboideus minor	3++
Pectoralis major	5	Levator scapulae	4
Pectoralis minor	5	Teres major	3++

Trapezius		Teres minor	3++
upper	5		
middle	5	Sternocleidomastoid	5
lower	5		

Besides downward and forward dislocation of right shoulder she had right ape thumb deformity with complete paralysis of the muscles of the thenar eminence

On review of the power chart it was obvious that in addition to the trapezius transfer for deltoid power she needed at least a good short rotator to reinforce subscapularis action Latissimus dorsi was chosen owing to its power being 4

She was operated upon under general anaesthesia for refixation of the snapped trapezius and posterior transfer of latissimus dorsi for reinforcement of the subscapularis action A second stage operation was undertaken to give active opposition of the thumb with the help of flexor digitorum sublimis tendon of the right ring finger through a pulley constructed from a part of the flexor carpi ulnaris tendon She was immobilised for 8 weeks in plaster before she was rehabilitated (Figures 36 and 37)

The excellent recovery is attributed to the presence of all the remaining intermediate group of muscles e g pectoralis major (5) and teres major et minor (3)

Case No 3

G B Female 17 years had right flail upper limb following attack of polio myelitis at the age of 3 years Her residual power distribution of shoulder joint complex was

Deltoid		Latissimus dorsi	3
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major	0	Levator scapulae	4
Pectoralis minor	2	Teres major	0
Trapezius		Teres minor	0
upper	3++		
middle	3++	Sternocleidomastoid	5
lower	3++		

She had downward and forward subluxation of the shoulder with complete *paralysis of the right elbow The forearm was fixed in full pronation and the hand* had slight residual power in the long flexors and extensors Intrinsics of the fingers and thumb

On reviewing the power chart the trapezius was thought to be insufficient for lifting the arm at the shoulder The upper short rotator *i e* supraspinatus required



Figure 36 Figure 37

Figure 36 The figure shows vertical scar for classical Bateman procedure which failed in her case

Figure 37 The figure shows the ability to lift the shoulder overhead It also shows the corrected ape thumb in opposition

replacement Levator scapulae was considered to take over the function of supraspinatus if it was transferred to the anterior portion of the greater tuberosity The subscapularis required replacement and here latissimus dorsi was considered suitable to act as a backward glider and prevent at the same time forward subluxation of the shoulder

Elbow flexion was proposed to be given by the sternocleidomastoid with a bone block behind the humerus to limit extension Pronation deformity was to be corrected by rotational osteotomy and minor readjustment of power in the fingers and thumb was necessary to give stability of the wrist and efficient grip of the hand

She was operated upon under general anaesthesia Levator scapulae was transferred to the anterior portion of the greater tuberosity Latissimus dorsi was rerouted immediately below the insertion of infraspinatus taking it behind and below the posterior atrophied fibres of the deltoid The trapezius was implanted in the shaft below the tuberosities covering the rerouted latissimus dorsi and levator scapulae with the help of two screws

Immobilisation was carried out in the zero position with a post operative check up for possible subluxation No special rehabilitaton programme was given following removal of plaster after eight weeks Review on 7 3 64 shows good functional recovery (Figures 38 and 39)

Though serratus anterior had better power than latissimus dorsi still the latter

of the left hand and elbow though below normal was enough to carry out usual activities requiring little strength. Her power in the left shoulder joint complex was as follows

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	*upper* two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	*Rhomboideus minor*	4
Pectoralis major (except a few fibres flickering at the lower *part*)	0	Levator scapulae	4
		Teres major	3+
Pectoralis minor	4	Teres minor	3+
Trapezius		Sternocleidomastoid	5
upper	4		
middle	4		
lower	4		

Review of the power chart shows that trapezius could be transferred for deltoid power though possibly it required reinforcement. The supraspinatus required replacement and could be given by either levator scapulae or sternocleidomastoid. The sternocleidomastoid was chosen for transfer. The subscapularis power being zero required replacement by either anterior or posterior transfer. Power being absent in latissimus dorsi it could be given by either pectoralis minor (4) or upper two digitations of serratus anterior (4).

She was operated upon under general anaesthesia using sabre cut incision. In addition to trapezius transfer at the usual site the sternocleidomastoid and pectoralis minor were rerouted to anterior portion of the greater tuberosity and lesser tuberosity respectively. Post operative follow up shows recovery of abduction to about 130 in recumbency. There is some stiffness of shoulder and a distinct web is seen in the neck during contraction of sternocleidomastoid which possibly could be avoided by more careful dissection and taking the muscle under the deep cervical fascia. There is also a web in the posterior fold of axilla which is seen taut preventing the arm from falling when lying in bed (Figures 42-44).

The results in this case have been very poor both from cosmetic and functional points of view. The distinct web is seen in the neck with the arm in the hanging position. The active elevation beyond 60 is difficult owing to web contracture in the axilla. There is a distinct disturbed scapulo humeral rhythm when she is on her back. She will require revisional procedure in the neck and axilla for the webs and subsequent rehabilitation.

Figure 42 

Figure 44 

Figures 42–44 The figures show ability to lift the arm in the standing and lying position Webs in the axilla and in the neck are seen



Figure 43

Case No 6

B C Male 16 years was admitted with residual paralysis of the right upper limb after an attack of poliomyelitis in early childhood The limb was absolutely flail incapable of carrying out any work and dangling helplessly The right elbow was fixed in 170° extension forearm in supination wrist in dorsiflexion with very little power in the fingers and ape thumb deformity His shoulder had anterior and downward subluxation This is considered to be an extreme case where shoulder disarticulation might have to be considered (Figure 45) The power distribution of the right shoulder joint complex was

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4++
		lower six digitations	4++
Short rotators			
subscapularis	2	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major	0	Levator scapulae	4
Pectoralis minor	0	Teres major	1

Trapezius		Teres minor	1
upper	4		
middle	4	Sternocleidomastoid	5
lower	4		

The power distribution at the elbow forearm and hand

Biceps	2++	Supinator brevis	0
Brachialis anterior	1	Triceps	0
Long extensor of fingers	2+	All others	0
Extensor carpi ulnaris	4		
Flexor pollicis longus	4		

On reviewing the muscle power chart it was considered that the thumb required a plastic repair to get rid of contracture of the web between the thumb and index to bring it passively in opposition and a subsequent fusion at the carpo metacarpal joint and osteotomy to give useful mid prone position of the forearm Power of extensor carpi ulnaris could be used for long flexor power of the fingers wrist being arthrodesed in optimum position The above procedures were thought to be deferred till the shoulder was rehabilitated The shoulder joint complex needed the upper two digitations of serratus anterior to reinforce subscapularis levator scapulae for supraspinatus and trapezius for deltoid and active external rotation of humerus The elbow if it required additional power for lifting was to be given by sternocleidomastoid transfer

He was operated upon under general anaesthesia the first stage upper two digitations of serratus anterior were transferred to lesser tuberosity The levator scapulae was transferred to the anterior part of greater tuberosity and trapezius to the upper humerus below the tuberosities overlapping the levator scapulae and extending backward

On removal of plaster after 6 weeks he was rehabilitated The figures show his ability to lift the arm at the shoulder (Figures 46 48) It may be noted that the transfers corrected the subluxation and gave fullness to the delto pectoral triangle and roundness to the shoulder

The muscles of intermediate group have practically no power There was no other alternative than to choose upper two digitations of serratus anterior levator scapulae and trapezius though their power is a little below normal Excellent recovery of shoulder proves that muscles may be made to develop if favourably placed even though their power is poor It may also be noticed that the transfers corrected the subluxation and gave fullness to the delto pectoral hollow and roundness to the shoulder Being a retail fresh fruits shop keeper he is waiting for a vacation to get his forearm and hand surgically rehabilitated

Case No ·

B.M., Male · year had residual paralysis affecting the right upper limb after an attack of acute poliomyelitis at the age of 1 year His residual power of the muscles of the shoulder joint complex are

Figure 45



Figure 48



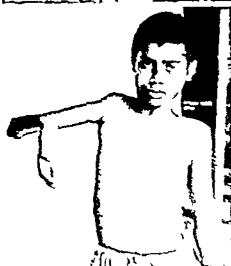


Figure 46



Figure 47

Figure 45 The figure shows the helpless right upper limb (described in the text)

Figures 46-48 The figures show ability to abduct the shoulder as seen from the front and behind Th roundness of the shoulder has been restored with delto pectoral hollow filled up The distance between the tip of shoulder and jugular notch is somewhat reduced

Deltoid		Latissimus dorsi	3
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	5



Figure 49



Figure 50

Figures 49 and 50 The figures show pre operative status and ability to lift and maintain the shoulder vertically overhead after operation

		lower six digitations	5
Short rotators			
subscapularis	1	Rhomboideus major	3++
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	3++
Pectoralis major	2	Levator scapulae	3++
Pectoralis minor	4	Teres major	4++
Trapezius		Teres minor	1
upper	4		
middle	4	Sternocleidomastoid	5
lower	4		

Shoulder was subluxated downward and forward Subscapularis test was positive with exaggerated posterior subluxation (Figure 15 page 46)

On reviewing the power chart it was seen that there were quite a few muscles for transfer Subscapularis required reinforcement supraspinatus a replacement in addition to transfer of trapezius In view of our experience with various combinations in transfer of muscle power and the best result obtained with upper two digitations of the serratus anterior levator scapulae and trapezius transfers it was decided to undertake the above procedures in this case

He was operated upon under general anaesthesia The upper two digitations of serratus anterior were transferred to lesser tuberosity the levator scapulae to anterior part of the greater tuberosity and trapezius to upper end of humerus

On removal of plaster after 6 weeks he was rehabilitated the figures show his ability to lift the arm overhead (Figure 49 and 50)

Perfect recovery within four weeks of removal of plaster with no exertion shows the importance of presence of some power in the intermediate group of muscles

Case No.8

M M M Male 8 years had residual paralysis of the left shoulder and elbow after an attack of poliomyelitis at the age of 4 years He had his residual power of the left shoulder joint complex distributed as follows

Deltoid		Latissimus dorsi	3
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	4
supraspinatus	0		
infraspinatus	0	Rhomboideus minor	4
Pectoralis major		Levator scapulae	4
clavicular head	1		
		Teres major	1+
Pectoralis major			
sternal head	2+	Teres minor	2+
Pectoralis minor	4+	Sternocleidomastoid	5
Trapezius			
upper	4+		
middle	4+		
lower	4+		

He had posterior dislocation of the shoulder while attempting protraction against resistance and anterior subluxation while rotating internally against resistance (Figure 51)

On reviewing the muscle power chart it was seen that he would require a strong elevator and replacement of the power of two short rotators It was decided to transfer trapezius levator scapulae and upper two digitations of serratus anterior at the usual sites The adjoining pictures show excellent recovery within a period of 6 weeks after removal of plaster (Figures 52-54)

Though the status of the muscles transferred for replacement of power is below normal still recovery has been excellent This shows the importance of intermediate group of muscles which have some residual power

Case No 9

B Nayar Male 17 years came with residual paralysis of the right upper extremity after an attack of acute anterior poliomyelitis in September 1946 His right elbow was flail The right pectoralis major was transferred for right biceps several years ago and this has regained power since the operation to about 3+ There is a web in the anterior fold of the axilla formed by the vessels and nerves of the transferred pectoralis major (Figure 55) Residual power of the right shoulder joint complex was as follows



Figure 51



Figure 53



Figure 54



Figure 52

Figure 51 The figure shows pre operative status of the patient

Figures 52-54 The figures show ability of the patient to lift the shoulder in all planes

Deltoid		Latissimus dorsi	3++
anterior	0		
middle	1	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
subscapularis	0	Rhomboideus major	2+
supraspinatus	1+		
infraspinatus	0	Rhomboideus minor	2+
Pectoralis major (transferred)	3+	Levator scapulae	4++
Pectoralis minor	4	Teres major	0
Trapezius		Teres minor	0
upper	4++		
middle	4++	Sternocleidomastoid	5
lower	4++		



Figure 55



Figure 56



Figure 57

Figure 55 The figure shows the pre operative status of the patient A scar on the belly of biceps is seen the scar on the chest is also faintly visible (the sites of previous operation)

Figure 56 The figure shows anterior subluxation on attempting internal rotation against resistance A skin fold is visible in the axilla (vide text)

Figure 57 The figure shows posterior subluxation on attempting abduction

The head dislocated forwards with attempted internal rotation against resistance (Figure 56) On the other hand as there was little power in supraspinatus and flicker in middle deltoid any attempt at abduction either actively or passively dislocated the shoulder posteriorly and upwards (Figure 57)

The case was peculiar as the shoulder could not be elevated passively beyond 140 and that too with the head in the dislocated position This set up a problem of stabilisation of the head in the fossa of the glenoid during elevation in all planes Postero superior dislocation prevented the use of a posterior glider acting from behind to replace subscapularis by latissimus dorsi This if done would aggravate the dislocation of the head backwards The other alternative of using upper two digitations of serratus anterior and/or pectoralis minor to replace the subscapularis power and to prevent posterior subluxation seemed rational The usual trapezius and levator scapulae to replace deltoid and reinforce supraspinatus respectively had to be done

He was operated upon under general anaesthesia The upper two digitations of serratus anterior were found to be of enough bulk to replace the subscapularis power and prevent posterior dislocation At the operation table when this was rerouted the head became stable while passively raising the arm at the shoulder No further reinforcement by pectoralis minor was thought necessary Trapezius and levator scapulae were transferred in the usual way The limb was immobilised *in such* position as to avoid stretching of the nerve to the pectoralis major Post operatively



Figure 58



Figure 59



Figure 60

Figures 58-60 The figures show post operative status and his ability to raise the shoulder overhead with a small weight in hand (½ kg) Shoulder stability has been regained The elbow flexes on raising the arm overhead due to complete absence of power in triceps

plaster was removed after eight weeks and rehabilitation was carried out by only active exercises (Figures 58 60)

Two directional instability of the shoulder posed a challenge that has been adequately met by transfer of upper two digitations of serratus anterior Functionally shoulder has regained almost full range of movement and power sufficient for normal activities He has only one active muscle belonging to the intermediate group having power 3+

Case No 10

Baby Dam Female 3 years came with residual paralysis of right upper extremity after an attack of acute poliomyelitis at the age of 6 months Residual power of the limb was as follows

Deltoid		Latissimus dorsi	0
anterior	0		
middle	0	Serratus anterior	
posterior	0	upper two digitations	4
		lower six digitations	4
Short rotators			
sub capularis	0	Rhomboideus major	3+
supra pinatus	0		
infra pinatus	0	Rhomboideus minor	3+
Pectoralis major	0	Levator scapulae	3++
Pectoralis minor	0	Teres major	0
Trapezius		Teres minor	0
upper	4		
lower	4	Sternocleidomastoid	5
middle	4		





Figure 61 *Figure 62*

Figures 61 and 62 The figures show post operative status and her ability to lift the shoulder in coronal plane The elbow being almost flail is seen flexed by gravity

The head of the humerus had forward and downward subluxation her right elbow was flail except for slight power in the flexors (?++) The forearm was fixed in pronation with diminished power of all the muscles She had partial paralysis of muscles of thenar eminence and diminished power in the intrinsics of the right hand

There was very little to choose to give active movements to the shoulder joint the trapezius upper two digitations of serratus anterior and the levator scapulae were the only muscles that could be spared

She was operated upon under general anaesthesia on 1 9 64 There being no power in any of the external rotators of the limb special care was taken during rerouting of trapezius to provide for active external rotation She was rehabilitated after removal of plaster at the end of eight weeks (Figures 61 and 62)

She is the youngest of the patients in our series External rotation is now possible with the help of the rerouted trapezius As expected she is unable to bring the limb to the side from the vertical overhead position in the coronal plane when lying on her side or back Lately she is developing a trick by which she flexes the shoulder with the help of the rerouted serratus to such a position when gravity helps to bring the arm to the side

CONCLUSION

Owing to lack of precise knowledge of the mechanism of the shoulder and the uncertainty of the available limited methods the results of our surgical rehabilitation of paralysed shoulder had been meagre We mainly confined our attention to the harnessing of the lifting power The trapezius was considered to be the best replacement Its insertion

had to be extended to the deltoid impression of the humerus. Leo Mayer's technique of sandwiching the belly and the freed margin of the trapezius between the two layers of fascia lata and extending it to the deltoid impression was tried in several cases. The results of this transfer have been poor. Patients treated by this method hardly developed enough power to lift the shoulder to 90°. With the passage of time even this range gradually diminished. On re-exploration the fascia elongated and was found to be anchored to the surrounding tissues by fibrous lacy strands extending from both the surfaces. These caused loss of lifting power.

We later tried isolated Bateman's procedure. This also failed to give the expected results in 75 per cent of our cases. The genuine flail shoulder with loss of short rotators gave uniformly poor results. Besides, rerouting the trapezius to the tuberosity gives less leverage and consequently enormous power is required to give adequate lifting force.

In some of our cases where the girdle muscles were strong we did arthrodesis generally by Brittain's technique. We experienced difficulty in obtaining a rigid fusion. The overall results were far from satisfactory. The arm could not be raised to more than about 120° in the most successful cases. In successful arthrodesis we found that the girdle muscles developed to a remarkable extent almost like those of an athlete, and in most cases more than those on the sound side. The muscles that developed were trapezius, serratus anterior and rhomboids. Our experience with the paralysed shoulder has been mostly between the ages of three and eighteen years. In the very young group in my earlier practice I used to postpone the arthrodesis owing to its possibility of failure till such time that the patient attained adolescence. That was also considered a great handicap particularly in right handed children.

The uncertain results of all these procedures led us to the enquiry of the causes of failure. With better knowledge of the shoulder mechanism and the action of the various muscles of the shoulder joint complex we arrived at a conclusion that besides the lifting power provided by what has been termed in the preceding chapters prime mover power to effect the gliding of the head of the humerus in two planes and its phasic fixation on the glenoid at each instant of elevation is required.

The three steering muscles, subscapularis, supraspinatus and infraspinatus, instead of acting as three isolated units behave as a hood

over the head of the humerus gaining continuous attachment to the lesser and greater tuberosities of the humerus (musculo-tendinous cuff of Codman) The particular muscle fibres of this musculotendinous cuff falling in the plane of movement contract to help the prime mover from the initial stages of elevation The power of the coplaner contracting muscle fibres initiates and maintains the elevation to 120 when the action potential reaches its maximum The inevitable gliding of humeral head (*vide infra*) takes place in this plane as the elevation progresses The other fibres anterior and posterior to these take over the steering function of gliding the head in the glenoid at a little later stage of elevation to bring the arm overhead This has been proved electromyographically We find that during elevation in the scapular plane supraspinatus helps the lifting force of the prime mover in the earlier and subscapularis at a later phase Likewise in flexion the supraspinatus helps steering action as shown by its later development of power while the subscapularis develops its power at an earlier phase

The mechanical advantage of the steering action in two planes is enhanced if the muscles act close to the bend of the axes of the head and neck and of the shaft This has been corroborated mathematically

The intermediate group of four muscles have their role in lifting by the gliding and depressor action The peculiarity of the tendons near their insertions helps the above actions

Besides these the scapular blade requires fixation in the setting phase of the scapula and a force couple to rotate particularly during the later stages of elevation of the shoulder The fixation and rotation of the scapula were analysed and found to be mainly affected by rhomboids levator scapulae pectoralis minor serratus anterior and trapezius In other words we have quite a lot of reserve in case the lifting force required is heavy The scapula would have a tendency to roll over the shoulder in their absence The question arose how far we could draw from this reserve without affecting the fixation and rotation of the scapula The levator scapulae upper two digitations of serratus anterior pectoralis minor and trapezius were thought to be dispensable maximum in the above respect The rhomboids and the lower six digitations of the serratus anterior would both act as fixator and rotator of the scapula The inevitable upward and forward movement of the scapula over the chest wall is carried out by the force transmitted through the rotation of the scapula by this spare rotator couple

We have seen that powerful girdle muscles are necessary to obtain

good results in arthrodesis. This is due to elongated leverage from fixation of the joint and movement of the girdle with the humerus in one piece round the scapulo thoracic joint. The fulcrum is thus shifted from the gleno-humeral joint to the scapulo thoracic. The very fact that strong girdle muscles are required for fixation of the shoulder defeats the aim of the principles of rehabilitation. When we have good power in girdle muscles we can spare some of these muscles for lifting, gliding and fixation at the gleno-humeral joint level while retaining the minimum for rotation and fixation of the scapula. Therefore it may be assumed that there cannot be any indication for arthrodesis in a flail shoulder. A mobile shoulder using part of the girdle muscles can be made to function more efficiently than an arthrodesed shoulder.

In other words past workers confined themselves to the development of techniques of the operations rather than to the principles of rehabilitation of a post polio paralysed shoulder. Therefore cases having good residual power in short rotators and/or intermediate group had good results with classical trapezius transfer. Cases where these muscles were more severely affected the results were poor and a total failure when these muscles were completely paralysed.

Lack of appreciation of the multiaxial nature of the gleno-humeral joint, change of contact surface with elevation and therefore of the fulcrum, bent anatomical axis, role of different forces at different levels in such a system, role of steering and depressor group of muscles besides the prime movers, zero position of the shoulder joint, essential movements at the proximal end (fulcrum) and its equivalent at the distal end probably stood in the way of evolution of surgery of rehabilitation of a post polio paralysed shoulder.

A modification of Bateman's trapezius transfer is used to give the lifting power at a greater mechanical advantage. Extensive mobilisation from the whole of the spine of the scapula keeping the implanting area as wide as possible facilitates more distal rerouting on the shaft of the humerus and gives a wider angle of pull. The multiple crushing of acromion in continuity helps to take the curve of the narrow shaft during rerouting.

For reinforcement or replacement of the subscapularis power upper two digitations of serratus anterior, pectoralis minor, part or whole of pectoralis major with bundled tendon of insertion and levator scapulae or a substitute acting from above (*vide supra*) may be used either singly or in combination. The direction of the fibres of the first three replacements conforms more to the normal direction of the fibres of

subscapularis and therefore these replacements are more suitable than the last transfer where the direction of the fibres is from above and does not fully satisfy the criteria of subscapularis replacement All these transfers act as posterior glider acting from the front

The posterior glider can also be reconstructed with the help of the muscles from the posterior aspect of the shoulder rerouting immediately below the lower limit of the greater tuberosity The muscles that can be used as posterior glider acting from behind are latissimus dorsi and teres major either singly or in combination Infraspinatus when paralysed does not require replacement *(vide supra)*

The vertical glider supraspinatus commences its action from the beginning of the elevation in the scapular plane Its replacement or reinforcement can be obtained by levator scapulae sternocleidomastoid scalenus anterior and scalenus medius Of these the first two gave good results The others may also be tried as their direction of fibres is more or less identical with the first two transfers and therefore the results are expected to be good

The muscles can be used in various combinations There are always one or two muscles available provided the girdle has a fair control of movement

The procedures are best carried out with the sabre cut incision and erasion of the deltoid from its origin without any subsequent repair One or more counter incisions in the axilla to deliver the transposed muscles before rerouting are used Post operative immobilisation in zero position for six to eight weeks is carried out as a routine measure Subsequent rehabilitation showed recovery in all the cases though complications and difficulties of fixation of the trapezius with the shaft of the humerus were encountered

The procedures almost invariably give near normal control of the shoulder fill the hollow between the humerus and chest wall anteriorly roll back the head of the humerus in its position prevent subluxation and give reasonable function even in the most desparate cases

The negative attitude of management of flail shoulder needs revision by a positive approach Indications for arthrodesis have now been shown to be the ideal indications for giving an actively mobile shoulder Arthrodesis is losing its ground in the rehabilitation programme of the postpolio flail shoulder

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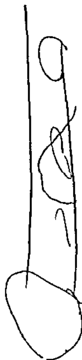
EXPERIMENTAL SKELETAL TUBERCULOSIS IN THE GUINEAPIG

A METHOD FOR PRODUCING LOCAL LESIONS AND AN AUTORADIOGRAPHIC STUDY OF THEIR ACCESSIBILITY TO TRITIUM LABELLED DIHYDROSTREPTOMYCIN

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From The Department of Orthopaedic Surgery (Head Anders Hulth M D)
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EXPERIMENTAL SKELETAL TUBERCULOSIS IN THE GUINEAPIG

A METHOD FOR PRODUCING LOCAL LESIONS AND AN AUTORADIOGRAPHIC STUDY OF THEIR ACCESSIBILITY TO TRITIUM-LABELLED DIHYDROSTREPTOMYCIN

BY
LARS LINDBERG

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PART I

A method for producing experimental skeletal tuberculous lesions in guineapigs

PART II

An autoradiographic study of the penetration of dihydrostreptomycin into *experimental tuberculous lesions in the skeleton*

PART I

I INTRODUCTION AND PURPOSE

This investigation is a link in a research programme of skeletal infections including skeletal tuberculosis One of the purposes of the investigation was to devise a method for producing tuberculous lesions in the skeleton of guineapigs i e a method hitherto missing in the long term study of slowly progressive tuberculous lesions in the skeleton Such model experiments in laboratory animals are often necessary in the investigation of the course of the tissue reaction and other features of an infection for example as well as of the effect of therapy It has hitherto not been possible to produce skeletal tuberculosis with a sufficiently low rate of progression All attempts have failed either becaus the animals soon died from rapidly progressing systemic tuberculosis or because the procedures induced skeletal lesions in far too small a percentage of the animals treated

For such a method of the experimental induction of tuberculous lesions to be accepted as satisfactory in the long term study of the individual foci it must satisfy the following requirements

1) it should not result in premature death of the animals from systemic tuberculosis

2) it must produce the tuberculous focus at a predetermined site and

3) it must produce such lesions in a high percentage of the animals treated

II HISTORICAL

A search of the literature failed to reveal more than a few investigations in which skeletal tuberculosis had been induced Muller (1886) produced foci in the tibia in goats by injecting tuberculous pus into the tibial artery Friedlaender (1902) reported the regular development of tuberculous lesions in various parts of the skeleton of 5 goats following an injection of a mixture of tubercle bacilli and lycopodium into the femoral artery Three of the animals died within 17 weeks and 2 were sacrificed after 31 weeks and 42 weeks respectively

Trudel (1933) reported the development of skeletal lesions in 75—85 % of rabbits following the injection of tubercle bacilli into the nutrient artery of the femur or the nutrient foramen of the femur The duration of survival of the animals was not given

Zappio and de Blasio (1935) succeeded in producing skeletal lesions in guinea

pigs by depositing 1 mg of tubercle bacilli directly into the tibia but the animals survived only 30—35 days

Boquet and Laporte (1936) who used rabbits claimed the development of skeletal lesions following intracutaneous injection of a special strain of tubercle bacilli but the data they give are not sufficient to allow reproduction of the experiment.

Koch (1950) produced skeletal tuberculosis in unvaccinated rabbits by depositing a small volume — about the size of a pin s head — of human tubercle bacilli through a hole drilled in the distal part of the femur Tuberculous lesions developed in the distal segment of the femur in the knee and in the thigh of all 14 animals infected. Little is said about the duration or rate of survival of the animals but at least one of them lived for 137 days after the inoculation

Bastos Mora and Portal (1953) injected tubercle bacilli directly into the femur of rabbits in one third of which skeletal lesions afterwards developed The duration of survival is not given. Several other workers in this field have also tried but failed to devise any satisfactory method for inducing local skeletal tuberculous lesions in rabbits let alone in guineapigs The lack of success was due either to early death of the animals from generalized tuberculosis or to the bacilli not obtaining a foothold in the bone marrow Of particular interest in this connection is the work by Doan and Sabin (1927) and Mandelstamm (1933) in which histological examination showed that intravenous injection of tubercle bacilli had produced lesions in the bone marrow but that these foci had healed (Doan and Sabin 1927) or had started to heal (Mandelstamm 1933) before the animal died from progressive tuberculosis of other organs

In a search for factors of importance in the induction of local tuberculous lesions it appeared but reasonable to peruse the literature on experimental non-tuberculous osteomyelitis which appears to resemble tuberculous osteomyelitis in origin and localisation

The literature on human non tuberculous osteomyelitis is enormous but not that on experimental investigations of the disease in animals Perusal of this part of the literature which dates back to the end of the 19th century when Rodet (1884) and Lexer (1894—98) published their first experiments shows that difficulties have been encountered in producing non tuberculous osteomyelitis in experimental animals As in experimental skeletal tuberculosis the animals often succumbed early (within a few days from septicaemia) and often before any demonstrable skeletal lesions had had time to develop

Of the methods that have proved successful in the production of non tuberculous osteomyelitis i e with a large percentage of takes and a relatively long survival of the animals the following deserve mentioning

1 Kuwahata (1930) induced Moller Barlow s disease in young guineapigs in which he then produced osteomyelitis by injecting staphylococci intravenously

2 Derizanov (1937 and 1938) sensitised rabbits by injecting horse serum subcutaneously The sensitised animals were later given horse serum + staphylococci into the tibia with slowly progressing staphylococcal osteomyelitis as a

result Csipak and Nem th (1953) and Bashinskaya (1959) have since used this method with success

4 Scheman et al (1941 and 1943) injected first sodium morrhuate (which tends to produce necrosis and is also used as a sclerosant in the treatment of varicose veins) through a hole drilled in the tibia of rabbits and half an hour later staphylococci through the same hole This procedure invariably produced staphylococcal osteomyelitis Unvaccinated animals survived at most 3 weeks while animals pretreated with a vaccination dose survived longer

5 On the basis of Letterer s theory (1948 and 1956) on the various stages of immunization Grundmann (1953) treated rabbits with staphylococcal vaccine and at various intervals after the vaccination he inject d staphylococci intrave nously and at the same time irradiated the tibia with a small dose of ultrasound which served as a well localized and well dosed trauma At a certain stage of immunization osteomyelitis of the tibia appeared *i e* at the site of the trauma

III PLAN OF INVESTIGATION

On the basis of preliminary experiments on more than 300 guineapigs it was decided to use unvaccinated animals (Series I) animals vaccinated with 0 3 mg BCG (Series II) and animals vaccinated with 40 5 mg tubercle bacilli (Series III) and the following experimental design

1 Drilling of a hole through the outer side of distal part of the femur

2 Insertion of pieces of Spongostan® impregnated with a suspension of tubercle bacilli through the hole into the marrow cavity

3 Histological and bacteriological examination of both the operated femur and the unoperated femur as well as the lungs liver and spleen of animals sacrificed 1 week to 6 months after insertion of the bacilli

4 Examination of the histological picture of the bone marrow for any effect of the actual surgical trauma and of the deposition of the pieces of Spongostan in the marrow cavity

5 Injection of a suspension of tubercle bacilli into the marrow cavity via the drilled hole to check the results reported by previous workers using this procedure

IV MATERIAL AND METHODS

A EXPERIMENTAL ANIMALS

It was decided to use the guineapig firstly because it has long been employed in tuberculosis research and secondly because the reactions of this animal to

human tubercle bacilli are so well known In addition, the guineapig is easy to keep it is readily infected with tubercle bacilli and it is small enough to be used in series large enough to allow reliable statistical analysis of the findings

The mouse white rat and golden hamster are so small that the operation would have been technically difficult Moreover the histopathological picture of tuberculosis in the mouse differs essentially from that in the human being in the guineapig and in several other experimental animals (Pagel 1940, Raleigh and Youmans 1948 Stewart 1950 Hurni et al 1951 Grun and Klinner 1952 Lack 1956 Pathologie der Laboratoriumstiere 1958 Ippen 1959) Some authors claim that the guineapig is the animal of choice in experimental skeletal tuberculosis (Feldman and Hinshaw 1945 Steenken 1949) It would appear that the only animal that could have been used satisfactorily instead of guineapig is the rabbit

In animal experiments it is of paramount importance that all procedures be standardized to avoid the introduction of unknown factors and to facilitate later reproduction of the experiments (Feldman and Hinshaw 1945 Raleigh and Youmans 1948, Hurni and Ragaz 1951 Spiess 1953)

In preliminary experiments not accounted for here the animals used had been obtained from A B Anticimex Breeding Station near Stockholm This station was however, closed down before the present investigation for which the animals were purchased from the breeder who regularly supplies guineapigs to the Department of Bacteriology, Malmo General Hospital

The animals weighed 200 gm when purchased this corresponds to an age of 8 weeks so that the animals could be operated upon before the epiphyseal plate had fused (Robertson 1927 Thompson and Dubos 1938)

The animals were kept in the same stable They were fed on hay mainly timothy and in summer on fresh timothy grass They were also given crushed oats and crushed barley supplemented in winter by cod liver oil and mangels *ad lib* instead of water The animals used in the various experiments were selected irrespective of sex

B TUBERCLE BACILLI

Strain H 37 Rv from the Central Bacteriological Laboratory of Stockholm City was used This strain is passed through guineapigs twice a year Between the animal passages it is recultured at least once a month on Lowenstein Jensen medium

The bacilli used for inoculation of the animals were cultured in the following way

From test tubes containing Lowenstein Jensen medium in which the bacilli were cultured 10 platinum loopfuls of the culture were transferred to a dish The colonies were homogenised with a glass rod and then suspended in 5 ml of physiological saline This suspension was cultured further in test tubes containing 5 ml of liquid Dubos medium To each tube was added 0 5 ml of the suspension The tubes were then covered — though not airtight — with a metal cap and

allowed to stand for a week at 37° C during which they were thoroughly shaken once a day

At the same time 5 pieces of Spongostan (see page 17) were placed in each of a series of test tubes containing 5 ml of Dubos medium These tubes were also covered with a metal cap and kept at 37° C for a week after which their contents were examined for growth This was done to check that the pieces of Spongostan had not been contaminated Preliminary experiments had shown that the pieces of Spongostan are liable to become infected when being cut out and handled

After one week s incubation at 37° C the suspension was vigorously shaken after which 1 ml of the culture was transferred to the above mentioned tubes containing Spongostan and culture medium These tubes were re incubated one week at 37° C during which they were thoroughly shaken once a day Tubes in which contamination was suspected were rejected On several occasions the purity of the cultures was checked by microscopic examination of stained smears

When the pieces of Spongostan were treated in this way embedded in paraffin cut into microscopic sections and stained with Ziehl Neelsen stain they were seen to contain numerous tubercle bacilli in the pores of the Spongostan

In experimental tuberculosis the rate and duration of survival of the animals the course of the disease and the histopathological picture vary with the size of the inoculum. The inoculum should therefore preferentially contain a predetermined number of bacilli (Feldman and Hinshaw 1945 Raleigh and Youmans 1948 Rosenthal 1957) In the method used in this investigation it was not possible to calculate the size of the inoculum because the bacilli were situated in the pores of the Spongostan This disadvantage was however not a serious one because it did not impair the usefulness of the method

C VACCINATION

A troublesome problem in experimental skeletal tuberculosis is the short duration of survival of the animals owing to massive spread of tubercle bacilli This problem is serious because a typical skeletal lesion with reactive changes requires a fairly long time to develop The duration of survival can be prolonged by previous vaccination with BCG (Bogen and Loomis 1935 Spiess 1953 Griesbach 1954 Rosenthal 1957)

The duration of survival of vaccinated animals varies with the interval between vaccination and superinfection According to Bogen and Loomis (1935) in guineapigs vaccinated with doses between 0 0001 mg and 100 mg BCG resistance to tuberculosis begins to increase about 2 weeks after vaccination and is clearly increased after a further 2 weeks In their animals the resistance was largely the same after 2 years In the present experiments the animals were superinfected 2—3½ months after vaccination had been started (*i e*, 1—2 months after conclusion of vaccination)

According to some authors immunological factors may also decide the site and

location of an infection (Lurie 1939 and 1942 Letterer 1948 and 1956 Csipak and Nemeth 1953 Grundmann 1953, Csipak et al 1954 Strom 1955, Csipak 1956 Rosenthal 1957 Freerksen and Meissner 1960) These factors are commented upon in the Discussion (page 42)

In the present work the experimental animals were vaccinated for two reasons to prolong the duration of survival and secondly if possible to produce at the site of inoculation a reaction which according to the authors referred to above may be of importance for locating an infectious skeletal focus

When purchased and again just before use the animals were examined with intracutaneous injection into the right flank of 0 1 ml of tuberculin diluted 1 100 All animals in which the reaction was equivocal were rejected The experiments were carried out on three series of animals

Series I consisted of unvaccinated animals So that the animals in all three series could be operated upon at the same age the unvaccinated animals in this series were kept untreated in the stable until vaccination of the animals in series II and III had been concluded

Series II was made up of animals vaccinated with 0 3 mg of BCG The animals were vaccinated with 0 2 ml freeze dried BCG vaccine 0 5 mg bacilli/ml, wet weight subcutaneously in the neck three times at one week intervals Six weeks to two months after the last vaccination the tuberculin test was performed and reactions characterised by a palpable thickening with erythema at least 10 mm in diameter after 2 and 3 days were said to be positive All BCG vaccine was obtained from Statens BCG laboratorium Gothenburg

Series III consisted of animals vaccinated with 40 5 mg bacilli The animals were vaccinated in the way d scribed below They were first given an intraperitoneal injection of 1 ml and a subcutaneous injection of 0 5 ml BCG vaccine containing 20 mg bacilli/ml wet weight This was followed one week later by administration of 0 15 ml of a paraffin oil suspension of killed bovine tubercle bacilli strain K3 10 mg bacilli/ml wet weight once a week for 7 weeks The suspension was obtained from Statens Bakteriologiska Laboratorium, Stockholm The injections were given *s c* at different sites in the neck and schoulders A tuberculin test was done 1 month after the last injection of bacilli The reaction was read after 2 and 3 days All animals showed a positive reaction with thickening and reddening of the skin over an area of 1 5×1 5 to 3×3 cm This area was characterised by a central pale necrotic area surrounded by a margin of intense reddening 2—4 mm wide After a further few days the necrotic tissue was shed leaving behind a sore This reaction is in agreement with the observations made by Wassermann (1962 and personal communication 1963)

D DEPOSITION OF TUBERCLE BACILLI INTO MARROW CAVITY

Previous publications give but little information on the possible factors responsible for the location of infections in a bone and its marrow cavity The present method of infection was therefore entirely empirical No attempts were

made to simulate infection by a normal route the purpose of the method being solely to produce a local lesion at a predetermined site in the skeleton.

1 *Choice of site of infection*

It was decided to use the lower part of the femur because it is readily accessible and because in human tuberculous and staphylococcal osteomyelitis this part of the skeleton is not uncommonly affected This site satisfies some of the conditions which previous workers believe to be necessary for osteomyelitis to develop there e g the bone has red marrow and the epiphyseal plate is not fused (Randerath 1931 Thompson and Dubos 1939)

2 *Operation technique*

The operation was performed under intraperitoneal anaesthesia 0 3 ml of Mebumal for veterinary use was mixed with 0 7 ml physiological saline Of this mixture 0 2 ml/100 g bodyweight was given intraperitoneally 5—10 % of the animals died while under the anaesthesia The hair on the lateral side of the left leg was cut off with scissors The skin over the intended site of the incision was washed with a solution of benzalkonium chloride or the like An incision 2—3 cm long was made through the skin in the longitudinal direction of the femur after which the femur was readily approached between the muscles with only slight loss of blood The edges of the wound were held apart with small elastic retractors With a dental burr 1 2 mm in diameter an oblique hole was drilled in mediodistal direction at the junction between the distal metaphysis and the diaphysis A piece of Spongostan containing tubercle bacilli was inserted through this hole Blood and bacterial suspension extruded from the piece of Spongostan were swabbed up after which the wound was closed The operation required 5—10 minutes

At operation attempts were made to deposit the bacilli in the distal metaphysis But this was often difficult without involving the risk of penetrating the epiphyseal plate The bacilli were therefore usually deposited at the junction between the metaphysis and the diaphysis

3 *Spongostan*

Spongostan is a hardened porous gelatin spongy substance manufactured by Ferrosan Malmo It is used as a haemostatic in surgery In the present investigation it was used as a carrier or receptacle for depositing the tubercle bacilli into the bone marrow cavity

In an attempt to retain the bacilli at the site where they were deposited a search was made for a carrier substance that is fairly rapidly resorbed and that is practically inert Various substances were considered such as polyvinylalcohol (resorbable) or polyvinyl sponge (not resorbable) both of which are practically inert (van Winkle 1960), methylcellulose (Hueper 1942 and 1944 Hueper et al 1942) or hydroxyethylocellulose (Jullander 1960 and personal unpublished ex

periments) Spongostan was however selected because it fills the aforementioned requirements and because its behaviour when deposited into living tissue is well known (Correll et al 1945 Jenkins and Clarke 1945 Jenkins et al 1946 Jenkins 1947 Bing 1947 MacDonald and Matthews 1947)

Previous authors have found sterile Spongostan deposited in various organs (liver kidney subcutis) of experimental animals to be resorbed within about 5 weeks No experiments had been performed to study the rate of resorption in a medullary cavity The Spongostan is said to be removed by macrophages and giant cells The tissue reaction was judged as only mild much milder than round suture silk catgut and pieces of muscle for example It was reminiscent of that around a blood clot When non sterile Spongostan was placed in the tissues it was mainly polynuclear cells that appeared and then the sponge was resorbed much more rapidly and disappeared within one week

With the aid of a trephine 3 mm in diameter cylinders were removed under sterile precautions from commercially available sheets of Spongostan about 1 5 cm thick After removal and consequent expansion these cylinders were about 1 cm high and 3—4 mm in diameter

As mentioned on page 15 these cylinders were placed in test tubes containing tubercle bacilli suspended in Dubos liquid medium Five cylinders were placed in each tube

E HISTOLOGICAL PREPARATIONS

In series I—III the entire operated left femur the unoperated right femur and pieces of the lungs liver and spleen were removed for histological examination The necropsy specimens of the lungs liver and spleen were excised from a predetermined part of each of the organs The tissue specimens were placed immediately in 10 % formalin and 1—4 weeks later they were sectioned and stained with haematoxylin eosin and according to van Gieson and often also according to Ziehl Neelsen

The bones were decalcified with trichloracetic acid or with formic acid or nitric acid or by the method of Parengi On one occasion the operated bone was decalcified electrolytically Only in the electrolytically decalcified bone did staining acording to Ziehl Neelsen show acid fast rods It would appear that the first four methods abolish or severely reduce the stainability of acid fast rods according to Ziehl Neelsen Histological examination of bones decalcified by the four aforementioned routine methods showed a typical feature of tuberculosis but no acid fast rods in slides stained according to Ziehl Neelsen That the animals really had tuberculosis was apparent from sections of the lungs liver and spleen, which showed not only the typical picture but also acid fast rods when stained according to Ziehl Neelsen The diagnosis of tuberculosis was also confirmed by the positive results of culture of the bone marrow (page 41)

The examination of sections stained according to Ziehl Neelsen was regarded only as a supplementary method because the procedure is time consuming and if the findings are negative several sections should be examined Examination of

sections stained by this method was therefore confined mainly to those cases in which the changes of minute foci in the liver and in the spleen for example were dubious In these cases demonstration of acid fast rods was useful

F CONTROL SERIES

1 *Surgical trauma*

In order to check the effect the surgical trauma *per se* had on the histological picture 32 animals were subjected to sham operations *i e* the same operation as that performed on th experimental animals but without insertion of the Spongostan and bacteria

The animals were sacrificed after various intervals *viz* 2 4 6 and 9 days and 2 3 4 5 6 7 8 and 10 weeks The legs operated upon were removed decalcified sectioned stained and examined

Results

In animals killed on *the 2nd day* after the operation a haematoma and bone and other tissue fragments were seen at the site of intervention The haematoma extended through the drilled hole and into the medullary cavity Some areas showed incipient cell prolifera tion from the endosteum

By *the 4th day* a fair amount of granulation tissue had formed This tissue contained bone fragments surrounded by numerous osteoclasts and osteoid trabeculae were beginning to appear

By *the 6th day* the entire haematoma was invaded by granulation tissue and osteoid callus was fairly abundant Periosteal callus was now seen in those areas around the drilled hole where periosteum had not been scraped off during the operation

By *the 9th day* all or almost all of the granulation tissue in the medullary cavity had been replaced by endosteal callus in the form of a well developed trabecular system In areas where the periosteum had not ben scraped off a similar periosteal callus had formed The masses of callus extended along both the inside and the outside of the orifices of the burred hole

After *2—3 weeks* the callus appeared to be fully developed The osteoblast seams were no longer conspicuous and red bone marrow had begun to extend between the trabeculae

After *4 weeks* the resorption of the callus in the medullary cavity was so advanced that the most of the bone trabeculae had disappeared and after *5 weeks* residual callus was seen in only one of the 4 preparations studied

After *6 7 8 and 10 weeks* small scattered rests of bone fragments were seen in the marrow which was otherwise of normal appearance

In a few preparations removed on the 4th day or later the preparations showed no sequelae after the operation trauma This was probably because the reaction to the trauma in these cases was so small that it did not reach the middle of the marrow cavity *i e* that part of the marrow sectioned and examined

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The last pieces of Spongostan were resorbed during *the 6th to 8th weeks* A few preparations examined after this period showed small scars of connective tissue rich in cells and containing some minute rests of Spongostan and a few small pieces of necrotic bone This picture represents one of the last stages of resorption of Spongostan before the histological picture of the red bone marrow again becomes normal During this time the resorption of the bony callus became more rapid

From *the 9th week* onwards none of the preparations contained any Spongostan and apart from a few small bone fragments *i e* rests of callus in some of the preparations the changes had been replaced by normal red bone marrow

In some preparations from animals killed soon after the operation only little or even no Spongostan could be detected This was probably because the sections studied had missed the Spongostan It was often necessary to study serial sections before any Spongostan could be found

Comparison of the marrow after a sham operation without insertion of Spongostan and with Spongostan revealed some differences in the course of healing but the picture of the site of the operation at the end of the study period after 10—12 weeks was the same *i e* normal red marrow with some small bone trabeculae which might have been rests of callus The differences in the course of healing of the two types of operations were

the callus formed persisted 1—2 weeks longer in the series in which Spongostan was inserted in the marrow cavity and

the reaction in and round the Spongostan which was missing in the first series The Spongostan was however resorbed within about 8 weeks after which the bone marrow was of normal appearance without any traces of cicatricious tissue

This final picture was seen after 5—6 weeks in the series operated upon without Spongostan and after 6—9 weeks in the series subjected to the sham operation with insertion of Spongostan

3 *Operation and injection of tubercle bacilli into the bone marrow*

In order to check the published results of injection of bacilli directly into the marrow cavity (pages 11—12) 16 unvaccinated guineapigs were operated upon in the way described 0 05 ml of a suspension of tubercle bacilli prepared in the way described (pages 14—15) was injected through the drilled hole Two animals were killed every other week Five of the animals died during the experiment and thereby shortened the experimental period to 12 weeks The legs operated upon were removed and examined histologically in the usual way

Results

After *2 weeks* No focus at site of operation Several small foci scattered about in the marrow

After *4 weeks* One small focus at site of operation in both animals Several small foci scattered about in the marrow

After *6 weeks* No focus at site of operation Several small foci scattered about in the marrow

After *8 weeks* One small focus at site of operation in one of the animals Several small foci scattered about in the marrow

After *10 weeks* A large abscess at the site of the operation in one of the animals Several small foci scattered about in the marrow

After *12 weeks* No focus at site of operation A few scattered foci in the marrow

Of this series of 16 animals an abscess was seen at the site of operation in only 1 and small foci in only 3 As in the main experiments described on pages 22—40 (Series I—III) small foci of epithelioid cells were also found out in the medullary cavity The results are in agreement with those found by previous workers using this procedure *ie* progressive tuberculosis at the site of inoculation developed in only a few of the animals used

Already in animals killed after 4—6 weeks necropsy revealed gross caseous foci in the lungs liver and spleen as well as in the lymph nodes

V RESULTS OF PERSONAL EXPERIMENTS*)

The animal experiments described in this chapter were preceded by preparatory experiments on more than 200 guineapigs in which principally the same method was used and in which largely the same results were obtained as those described below Since various technical details were modified during the elaboration of the method only the results obtained in the last 3 experimental series with the final experimental design are described here

Table 1 gives the intervals between the operation and sacrifice of the animals as well as the number of animals used for histological and bacteriological studies None of the animals in this experiment died spontaneously

In series I and III the experiments were stopped after 4 months and 3 months respectively because in preparatory experiments animals treated in the same way as in series I often died within 4 months and in those treated in the same way as in series III the skeletal lesions usually healed within 3 months

*)The valuation of the histo pathological preparations was supervised by professor Folke Linell M D Department of Pathology Malmo General Hospital University of Lund Malmo Sweden

TABLE 1

Survey of experimental animals in Series I—III

Interval between operation and sacrifice of animals	1 w	2 w	3 w	4 w	5 w	6 w	8 w	10 w	12 w	4 mths	5 mths	6 mths	
Series I													
Histological preparations	2	2	2	2	2	2	2	2	2	2	—	—	20
Culture of bacteria	—	1	1	1	1	—	1	—	1	—	—	—	6
Series II													
Histological preparations	2	3	3	2	3	3	2	2	2	2	2	1	27
Culture of bacteria	—	1	1	1	—	1	1	1	1	1	1	—	9
Series III													
Histological preparations	2	2	2	2	2	2	2	2	1	1	—	—	18
Culture of bacteria	—	1	1	1	—	1	1	1	—	—	—	—	6

A LESIONS IN THE OPERATED FEMUR

1 *Development in series I*

After *1 week* the major part of the medullary cavity at the site of the operation was filled with non tuberculous granulation tissue round a fairly large amount of Spongostan which was undergoing resorption Tissue fragments after the surgical trauma were also seen Osteoid trabeculae were observed in various areas No structures typical of tuber culosis were found at the site of operation

The upper medullary cavity exhibited small areas with diffuse accummulations of macrophages possibly a sign of incipient tuberculosis These areas also contained single giant cells

After *2 weeks* the area with granulation tissue at the site of the operation was the same size as after one week but the tissue had now begun to become tuberculous and contained numerous epithelioid cells macrophages and some giant cells of Langhan s type A previously newformed trabecular system round the granulation tissue was being resorbed by the tuberculous tissue and Howship s lacunae with clusters of osteoclasts were seen in several areas The diffuse accumulations of macrophages in the medullary cavity had now assumed a tuberculous appearance and contained epithelioid cells The bulk of the Spongostan had been resorbed but small fragments were still seen in all preparations

The lesions progressed and after *3 weeks* the foci at the site of operation had developed into productive tuberculous lesions with epithelioid cells and Langhan s cells They now filled the entire cross sectional area of the medullary cavity One focus showed signs of commencing central necrosis Both osseous destruction and bone newformation were seen in the periphery of the foci The small foci scattered in the medullary cavity now consisted mainly of epithelioid cells and contained a large number of giant cells One of the foci showed incipient central necrosis Spongostan fragments were still seen in one preparation

After *4 weeks* the necroses had increased in size and the last pieces of residual Spon[illegible]stan were seen The small epithelioid cell foci in the medullary cavity persisted un[illegible]ed

[illegible]rst fully developed abscesses were seen after *5 weeks* The foci had then in[illegible] *[illegible]ze and occupied one fourth to one third of the entire distal diaphyseal medul[illegible]* [illegible] The abscesses were made up of a central area of necrosis which merged [illegible]row border of epithelioid cells which was in turn surrounded by a thin cuff [illegible]rculous tissue with *inter alia* fibrous streaks and in some areas also bone [illegible] Largely the same picture was seen in all of the abscesses in series I II and III

The [illegible]se con[illegible]inued to increase at the expense of the productive granulation tissue and the a[illegible]s[illegible]s became larger so that after *6 weeks* they occupied the distal half of the m[illegible]dullary [illegible]avity down to the metaphysis Single small scattered epithelioid cell foci wer[illegible] s[illegible]en in the marrow

From th[illegible] *[illegible] of the 6th week to the end of the 4th month* when the experi ment was stopped all of the preparations except two showed a largely uniform picture namely a lar[illegible] abscess of principally the same structure as that described above The abscesses var[illegible]d in size the largest occupying the entire diaphyseal medullary cavity the smallest only the distal fifth

In two preparations (after 10 and 12 weeks) however the site of the operation

showed only one small focus occupying about one fourth of the cross sectional area of the medullary cavity Both lesions consisted largely of epithelioid cells and one of them showed a small necrosis

Scattered small foci were seen in practically all preparations and even in those animals in which no such foci were seen the presence of such lesions cannot be excluded because they may have been so small as to have been missed by the sections studied

2 *Development in series II*

After *1 week* the medullary cavity at the site of the operation was filled with non tuberculous granulation tissue This tissue contained *inter alia* numerous polynuclear cells and small bits of bone undergoing absorption Osteoid trabeculae had begun to form No fragments of Spongostan were found in any of the preparations

Out in the medullary cavity were small scattered groups of macrophages and epithelioid cells and in one preparation also numerous Langhan s cells

Already after *2 weeks* the distal part of the diaphyseal medullary cavity showed large abscesses In the central necrosis were numerous polynuclear leucocytes and around the necrotic centre was a broad cuff of granulation tissue which had assumed a tuberculous appearance and in several areas it contained bone fragments after the operation Intense bone newformation and bone destruction were seen in several areas The abscesses with the peripheral tissue reaction occupied the entire cross sectional area of the medullary cavity The abscesses were of largely the same structure as that in series I (page 24)

Small scattered clusters of epithelioid cells and macrophages sometimes with Langhan s cells were seen in the marrow of all preparations

After *3 weeks* no Spongostan fragments were demonstrable and after *4 weeks* the central necroses in the abscesses had become more caseous but otherwise the picture was largely unchanged

After *5 weeks* the tuberculous abscesses at the site of the operation began to decrease in size owing to the reactive bone newformation in the medullary cavity It is difficult to estimate how much the reactive bone formation had progressed because the extent of such format on in the medullary cavity varied with the level of the histological sections studied

In later preparations the healing process could be followed up to the disappearance of the abscesses in preparations of animals killed after *4 months*

The abscesses occupied a decreasing proport on of the cross sectional area of the me dullary cavity they sometimes increased in length but were forced back towards the centre of the medullary cavity by normal bone marrow and spongy bone developing between the wall of the abscess and the inner side of compact bone In some preparations especially in those from animals killed after 10 weeks the d stal part of the medullary cavity was entirely filled with a sclerotic trabecular system

After *4 months* the foci at the site of the operation had disappeared Healing had advanced and the distal fourth of the diaphyseal medullary cavity was filled with sclerotic trabeculae The trabecular interstices were filled with normal red bone marrow The trabecular system successively decreased in size and after *5 to 6 months* only some sparse thick trabeculae persisted free in the medullary cavity The last sign of tuber culosis at the site of operation a small necrotic centre possibly the remains of a once larger lesion surrounded by tuberculous tissue diffusely outlined against surrounding bone marrow was seen in a preparation from an animal killed after 5 months

Small scattered foci were seen in the bone marrow in practically all preparations from

the very beginning until the end of the 6th month after the operation They varied in size but were never as large as those at the actual site of the operation the smallest ones appearing to consist of only some tens of cells These foci were seen in the diaphysis metaphyses and epiphyses Some of them showed signs of central necrosis but broadly speaking their appearance remained unchanged during the entire experimental period

3 *Development in series III*

As in series I and II after *1 week* the medullary cavity at the site of the operation was full of non tuberculous granulation tissue with residual necrotic tissue and inflammatory cells Osteoid trabeculae had begun to form and fairly numerous fragments of Spongostan were found in the preparations

The marrow contained small scattered foci with *inter alia* epithelioid cells

Already after *2 weeks* abscesses of the previously described structure (see page 24) were seen at the site of the operation In one preparation the abscess extended down into the metaphysis Small fragments of Spongostan were still seen

Small scattered clusters of epithelioid cell were observed in the marrow

The abscesses persisted largely unchanged during the *3rd and 4th weeks* with certain variations from one animal to another After 3 weeks the Spongostan had disappeared

After *5—6 weeks* some of the foci had decreased in size owing to the formation of normal marrow between the compact bone and the wall of the abscess It is difficult to say when this healing had started because of the differences between the individual preparations It is possible that it had started already during the 3rd to 4th week

The healing process advanced and in the preparation from one of the animals killed after *8 weeks* the abscess had largely healed and left behind only a small remnant while an abscess was seen in the preparation from the other animal

After *10 weeks* the preparation from one animal showed no signs of tuberculosis while a large abscess occupying two thirds of the medullary cavity was found in the other Sclerotic trabecular systems still persisted at the site of the operation after 8 and 10 weeks even when the abscesses had disappeared

After *12 weeks* (one preparation) and *4 months* (one preparation) there were no signs of tuberculosis and only a small rest of a trabecular system was found at the site of the operation

From the 3rd week inclusive the small scattered clusters of epithelioid cells were sometimes missing and from the beginning of the 10 th week no such clusters were seen in the preparations

4 *Comparison between the three series*

a Lesions at the site of the operation

During the first week no tuberculous lesions developed in any of the series all showed only a non tuberculous reaction at the site of the operation (Fig 1)

In series I a productive focus developed during the 2nd and the 3rd weeks (Figs 2 and 3) and central necrosis began to develop after about 3 weeks (Fig 4), to increase in size during the 4th week and to develop into a typical abscess after the 5th week with a largely necrotic centre surrounded by a thin wall In series



Fig 1
Site of operation 1 week after operation Series I Htx eosin X6

I the abscesses then increased in size and after 6 weeks they occupied a large part of the medullary cavity (Figs 5 and 6) In all preparations except 2 large abscesses were then found throughout the experimental period i e until the end of the 4th month

In series II the fully developed abscesses appeared already after 2 weeks (Figs. 7 and 8) and they began to decrease in size after about 5 weeks and to disappear after about 4 month (Figs 9—13)

In series III the fully developed abscesses also appeared after 2 weeks (Fig 14) and the healing of the lesions at the site of the operation appeared to progress in the same way as in series II (Fig 15)

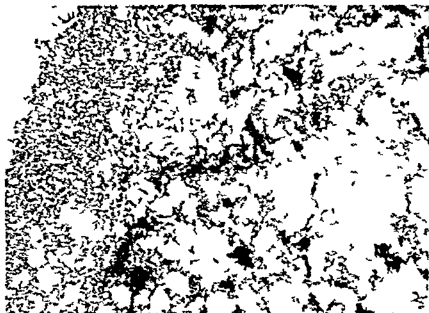


Fig 6
Necrosis 6 weeks after operation Series I van Gieson ×170



Fig 7
Central necroses surrounded by tuberculous productive tissue and newformed bone 2 weeks after operation Series II van Gieson ×9



Fig 8
Abscess 3 weeks after operation Series II Htx eosin ×6

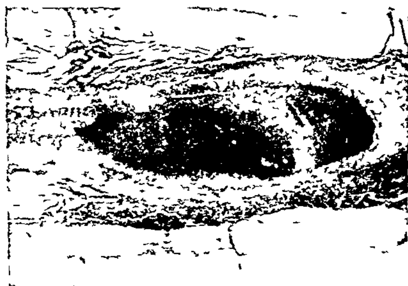


Fig 9
Abscess 6 weeks after operation Series II van Gieson ×20



Fig 14
Abscess 2 weeks after operation Series III van Gieson ×20



Fig 15
Healing abscess 6 weeks after operation Series III van Gieson ×20



Fig 16
Small focus in the bone marrow remote from the site of the operation 3 weeks after operation Htx-eosin ×170

b LESIONS IN THE MEDULLARY CAVITY OUTSIDE THE OPERATIVE FIELD

The small scattered foci seen remote from the site of application of bacilli (Fig 16) appeared after about 1 week in all 3 series and in almost every preparation in series I and II while in series III they were sometimes no longer demonstrable after 3 weeks and never from the 10th week on

B TUBERCULOUS LESIONS IN LUNGS LIVER SPLEEN AND THE UNOPERATED CONTRALATERAL FEMUR

1 *Development of pulmonary lesions*

In the evaluation of the results of this part of the investigation it should be borne in mind that only a piece of lung tissue about one fifth of the left lung was examined in every animal Tuberculous changes differing in type from thos described below may thus have occurred in those parts of the lungs that were not examined.

Series I

No histological signs of tuberculosis were seen during *the first 2 weeks* After *the 3rd—4th weeks* the pulmonary parenchyma began to show evidence of histologically non tuberculous scattered diffuse accumulations of macrophages which might have been a sign of incipient tuberculosis These diffuse accumulations of macrophages developed into epithelioid cell tubercles after *5—6 weeks* in some of the animals but not until after *8 weeks* were any large areas of productive tuberculous granulation tissue seen and then only in one animal while preparations from the other animal killed at that time showed areas with accumulations of macrophages After *10 weeks* only diffuse accumulations of macrophages were seen After *12 weeks and 4 months* epithelioid cellular foci were observed in all the preparations One of the foci showed signs of incipient necrosis

Thus no signs of tuberculosis were seen during the first 2 weeks They began to appear during the 3rd week in the form of histologically non tuberculous changes During the 5th—10th weeks tuberculous changes appeared *i e* epithelioid cell foci alternating with groups of macrophages in some of the 8 animals but not until after 12 weeks and 4 months did all the animals (4) exhibit foci of epithelioid cells

Series II

In this series the development of tuberculosis could not be followed clearly During the entire experimental period some preparations showed no histological evidence of tuberculosis at all or only histologically non tuberculous diffuse accumulations of macrophages or epithelioid cell foci

After *1—8 weeks* diffuse accumulations of macrophages were found in six preparations while signs of tuberculosis were missing in twelve After *10 weeks* the first epithelioid cell foci appeared in two preparations After *12 weeks 4 months and 5 months* no signs of tuberculosis were found in three preparations but diffuse accumulations of macrophages were observed in one preparation and epithelioid cells in two Incipient necrosis was seen in only one preparation from an animal killed at the end of the 4th month This preparation also contained epithelioid cells

Series III

As in series II during the entire experimental period preparations free from signs of tuberculosis alternated with preparations with diffuse accumulations of macrophages or epithelioid cell foci

Already after *1—2 weeks* tuberculous changes were suspected in two preparations but not in the other two After *3—6 weeks* diffuse accumulations of macrophages were found in three preparations but were missing in four After *8 weeks* the first large tuberculous focus with necrosis was seen in one of the preparations but only diffuse accumulations of macrophages in the other From the beginning of the *10th week to the end of the 4th month* inclusive one preparation showed groups of epithelioid cells one diffuse accumulation of macrophages and two showed no signs of tuberculosis

COMPARISON BETWEEN THE THREE SERIES

In series I no signs of tuberculosis were seen during the first 2 weeks not even the histologically non tuberculous accumulation of macrophages but from then on signs of tuberculosis were seen in all preparations throughout the rest of the experimental period In series II and III diffuse accumulations of macrophages possibly the initial sign of tuberculosis were seen already after 1 week but from then onwards many of the preparations showed no signs of tuberculosis

Compare also the results of bacterial culture of the pulmonary tissue (page 41)

2 *Development of lesions in the liver*

As in the examination of the lungs for tuberculosis only relatively small pieces of the liver were removed for histological examination so that changes other than those described below might have occurred in those parts of the liver that were not examined

Series I

After *1 week* no signs of tuberculosis were seen but after *2 weeks* both preparations showed single very small changes of non tuberculous type with some macrophages lymphocytes and central destruction Acid fast rods were found in one of these foci Also in preparations from animals killed at different intervals and in different series these small foci exhibited acid fast rods which were therefore regarded as a very early sign of tuberculosis The foci increased in size and number epithelioid cells and sometimes also Langhan s cells appeared so that after *4 weeks* small tuberculous foci were seen throughout the preparation Some of the lesions showed incipient central necrosis The now histologically tuberculous foci increased slowly in size and after *12 weeks* large and sometimes coalescent areas of tuberculous granulation tissue were seen over the entire area of the section After *4 months* lesions of largely the same type were seen as after 12 weeks they were however sparser than in the previous preparations which may have been due to differences between the individual animals But these preparations also showed small lesions of roughly the same type as those seen after two weeks consisting of some tens of macrophages and lymphocytes often also a giant cell These small lesions may have been due to secondary haematogenous spread of the bacilli

Series II

Already after *1 week* the small foci mentioned in series I and consisting of some tens of macrophages and lymphocytes and often containing a giant cell began to appear

After *2 weeks* the preparations showed not only such small foci but also a few larger lesions some of which were partly necrotic The lesions grew in size and after *3—4 weeks* numerous epithelioid cells were seen in several preparations

In later preparations *5 weeks—5 months* after operation the individual variation was wide and the development of the tuberculosis was no longer uniform Only in four preparations was there more advanced tuberculosis with large tuberculous lesions In half of the remaining preparations there were only small lesions and in the other half also somewhat larger ones

Series III

Already after *1 week* as in series II the aforementioned small foci began to appear These small lesions were typical of this series In sixteen of the eighteen preparations *1 week—12 weeks* after operation they were the main component Single larger productive foci were also seen in some of the preparations The foci varied somewhat in number One preparation showed not only numerous small fo i but also several large ones

Comparison between the three series

Series I showed no signs of tuberculosis during the first week but in the 2nd week small foci began to appear In series II and III the first small foci appeared after 1 week B cause of the wide variation of the different preparations it is not possible to compare the three series though it appears as if the foci were densest and largest in series I and least dense and smallest in series III

3 *Development of lesions in the spleen*

The entire ventral half of the spleen was used for histological examination

Series I

After *1 week* no tuberculous lesions were seen but after *2 weeks* scattered small clusters of epithelioid cells and macrophages appeared in both preparations The foci grew and after *3 weeks* there were numerous large productive lesions some with incipient central necrosis After *4 and 5 weeks* the appearance of the preparations was largely the same all of them showed small to large epithelioid cell foci some with central necroses After *6 8 10 12 weeks and 4 months* all the preparations contained a varying number of epithelioid cell foci

Series II

After *1 week* one of the preparations showed no signs of tuberculosis while the other one exhibited small groups of cells resembling macrophages or epithelioid cells These foci were of the same appearance as those described in the section on liver tuberculosis (page 37) After *2 weeks* one of the preparations exhibited only equivocal evidence of tuberculosis while another showed small epithelioid cells and the remainder a small group of macrophages and some giant cells as well as several giant cells scattered in the parenchyma some of Langhan s type — possibly early evidence of tuberculosis The

foci grew and after *3 to 4 weeks* they assumed a tuberculous appearance and numerous small and large groups of epithelioid cells were found in all of the preparations The foci appeared to be largest and most numerous at this time after which they began to decrease in size and number After *5 weeks* one of the preparations like those examined after 3 and 4 weeks contained numerous small and large foci In the remaining two there were sparse epithelioid cell foci of varying size After *6 8 10 and 12 weeks* and *4 5 and 6 months* no histological signs of tuberculosis were seen in three of the preparations from animals examined 6 weeks 4 months and 5 months respectively after the operation In one of the preparations from the animals killed after 6 months as well as in preparations from animals killed after 3—4 weeks there were numerous small and large groups of epithelioid cells In all the remaining twelve preparations only small epithelioid cells were seen usually sparse and scattered in the parenchyma

Series III

No definite signs of tuberculosis were seen after *1 week* In one preparation there were small accumulations of macrophages which might have been an early sign of tuberculosis After *2 weeks* there were no signs of tuberculosis After *3 weeks* one preparation showed no signs of tuberculosis while the other contained small sparse groups of epithelioid cells After *4 weeks* there were no definite signs of tuberculosis — one of the preparations contained a small group of epithelioid like cells but it was difficult to decide whether they were due to tuberculosis After *5 and 6 weeks* all the preparations contained fairly sparse epithel o d cell foci. After *8 weeks* one of the preparations showed no signs of tuberculosis while the other contained numerous large epithelioid cell foci After *10 a d 12 weeks* there were again no sign of tuberculosis in one preparation while the others exhibited small scattered foci of epithel oid cells In the last preparation from animals killed *4 months* after the operation there were large crowded foci of epithel oid cells occupying about half of the parenchyma

COMPARISON BETWEEN THE THREE SERIES

In s ries I and II the first tuberculous changes occurred at roughly the same tim *i e* during th first — second week From then on in series I foci were seen in all preparations throughout the rest of the experimental period while in series II tuberculosis was missing in three preparations during the p riod 6th week—5th month In series III the first tuberculous changes occurred 3 weeks after the operation after which the cours largely resembled that in series II, *i e* tuberculous lesions were missing in some of the preparations while productive foci of varying size were found in the remainder

4 *Tuberculosis of the unoperated contralateral femur*

Series I

There were no s gns of tub rculosis after *1 week* After *2 weeks* however the medullary cavity showed single very small areas with what appeared to be macrophages A giant cell was seen in one of the preparations This might have been the first histological sign of tuberculosis These small foci grew so that after *3 weeks* there were still very

small scattered miliary foci in the marrow From the *4th week to the 4th month* all the preparations showed miliary foci These foci varied in size from very small consisting of some 10 cells or more up to single foci occupying a third of the cross sectional area of the medullary cavity These foci however never reached the size of those seen at the site of inoculation no abscesses developed and there was no reactive connective tissue or bone newformation in their periphery The foci were scattered in the red bone marrow and were seen in the diaphysis metaphyses and epihyses as well as in the patella

Series II

Already *1 week* after the operation one preparation showed some very small groups of cells of the type described in the liver preparations from animals examined after 1 week in series II These foci might have been signs of incipient tuberculosis During the *2nd—5th weeks* miliary foci were seen in five of eleven preparations and from the *6th week to the 6th month* miliary foci were found in seven of fourteen preparations Evaluation of the negative preparations was difficult Some of them contained very small groups of cells which might have been of the same type as those seen in preparations from animals killed 1 week after the operation Since the bones were not serially sectioned small foci may have been missed Tuberculosis might thus have been present in some of these preparations As in series I foci were seen in all parts of the red marrow of the bone

Series III

Already *1 week* after the inoculation miliary foci were seen in both preparations After *2 weeks* one of the preparation showed definite miliary foci while the other was difficult to evaluate It might have contained one small focus From the *3rd week to the 4th month* when the experiment was stopped tuberculosis was seen in eight of fourteen preparations but not in the remaining six As in series II evaluation of the negative preparations was difficult In this series too foci were seen in all parts of the red bone marrow

COMPARISON BETWEEN THE THREE SERIES

In series I there were no histological signs of tuberculosis after 1 week but from then on miliary foci were seen in all of the preparations At 1 week one of the preparations in series II and both of them in series III showed histological signs of tuberculosis From then on signs of tuberculosis were missing in several of the preparations in these two series

Moreover in series I the foci were on the whole larger and more crowded than in series II and III

C CULTURE OF TISSUE FOR TUBERCLE BACILLI

Since the diagnosis of tuberculosis cannot be regarded as established without demonstration of tubercle bacilli in the tissue tissue specimens were removed and

cultured for tubercle bacilli In certain animals (Table 2) the diaphyseal marrow was removed from the operated femur and pieces from the lungs liver and spleen were removed under sterile conditions and treated in the following way

The pieces of the tissue were carefully homogenized in a mortar and treated for 10 minutes with 6 % sulphuric acid The crushed pieces of tissue were then suspended in 100 ml physiologic saline and centrifuged for 20 minutes after which the fluid was pipetted off and the sediment was cultured The sediment was cultured in 3 tubes containing solid Lowenstein Jensen medium and 1 containing Braun Lebeck s medium The rest of the sediment was filtered through a membrane and cultured on a plate with Lowenstein Jensen medium

The results were read after 4—8 weeks by inspection of the culture on Lowenstein Jensen medium and the plates and by examination of smears from the Braun Lebeck medium stained according to Ziehl Neelsen

The results of culture of the various organs were in good agreement with those obtained by histological methods It was checked by the niacin test that the strains isolated from the animals were of human type like strain H 37 Rv (Juhlin 1960)

TABLE 2

Results of culture for tubercle bacilli

Series	I (6 animals)						II (9 animals)									III (6 animals)					
Interval between operation and sacrifice in weeks	2	3	4	5	8	12	2	3	4	6	8	10	12	18	22	2	3	4	6	8	10
Bone marrow	+	+	+	+	+	+	+	+	+	—	C	+	—	—	C	+	+	+	—	+	+
Lung	+	+	+	+	+	+	+	+	+	+	—	+	—	—	—	—	+	—	—	—	—
Liver	+	+	+	+	+	+	+	+	+	+	+	+	—	—	—	+	+	+	+	—	+
Spleen	+	+	+	+	+	+	+	+	+	+	+	+	+	—	+	+	+	+	+	—	+

+ = growth of Mycobacterium tuberculosis

— = no growth of Mycobacterium tuberculosis

C = contaminated

VI DISCUSSION

A FACTORS LOCATING AN INFECTION IN THE SKELETON

In previous investigations by other workers in this field the animals usually survived for only a short time and skeletal lesions occurred in only a few of them. Since the purpose of the present investigation was to devise a method for long term studies not only the literature on experimental skeletal tuberculosis but also that on experimental non tuberculous infections of the skeleton was perused it sounding reasonable to assume that some factors locating the infection in the skeleton may be the same in both types of disease

Various suggestions have been offered for the location of the lesions in the skeleton *e g* trauma (Friedlaender 1902 Trudel 1933, Grundmann 1953) bacterial emboli (Friedlaender 1902 Mandelstamm 1933 Mayer et al 1954 Tsuge and Tomochika 1955) vascular anatomy of the metaphysis (Lexer 1904 Siegmund 1948 Buchman 1959) paucity of phagocyting elements in the metaphysis (Hobo 1921) straining of the epiphyses with local haematoma as a result (Robertson 1927) C-avitaminosis (Kuwahata 1930) chemical affinity between bacteria and the body tissue (Rost 1913) vascular spasm (Baskinskaya 1959) allergic reactions (Denzanow 1937 Csipak et al 1953 and 1954 Grundmann 1953 Csipak 1956) the presence of red bone marrow (Randerath 1931)

A critical analysis of the above mentioned theories would fall beyond the scope of the present investigation Therefore suffice it here to give a few remarks on some pertinent factors in this experiment

1 *Site of inoculation*

The lower femur was selected because it has some of the aforementioned anatomical structures considered of importance in the location of an infection to the skeleton Besides this the lower femur is not an uncommon site of tuberculous and non tuberculous osteomyelitis in human beings

2 *Trauma*

Several of the above mentioned authors discuss the significance of the trauma That trauma can contribute to location of the disease to the skeleton is probable The bacteria or the host must however possess certain properties for an infection to occur at the site of the trauma e g a certain level of immunity of the host a certain virulence of the bacteria Thus trauma is only a contributory cause This had been discussed especially by Grundmann (1953)

The local tissue destruction after a trauma is also probably of significance in

the location of the infection Certain experiments (Derizanov 1937 and 1938 Scheman et al 1941 and 1942 Csipak et al 1953 and 1954 Csipak 1956 Baskinskaya 1959 and personal unpublished experiments) have shown that a skeletal focus can be produced if bacteria are injected into a local necrosis of the bone marrow

3 *Tissue reaction around the Spongostan*

The reaction occurring around the Spongostan introduced into the bone marrow may also tend to locate the infection it being a commonplace that infection round a foreign body is obstinate and that healing often promptly occurs after removal of the foreign body Spongostan was however chosen because it is practically inert and therefore does not substantially interfere with the picture of the infection Spongostan is also fairly readily resorbed — in series I—III already within 2—4 weeks

4 *Depot effect*

The fact that injection of bacteria into the actual bone marrow of the animals usually fails to produce foci at the site of injection may be explained by the assumption that a large proportion of the bacteria are rapidly transported away with the blood Deposition of the Spongostan and tubercle bacilli in the bone in the way described prolongs the duration of contact between the local tissue and the tubercle bacilli and thereby increases the possibility of development of a local lesion

5 *Immunological status of the experimental animals*

Experiments carried out by Lurie (1939) Spiess (1953) Spiess and Poppe (1954) and Strom (1955) suggest that tubercle bacilli are retained longer at the site of inoculation in vaccinated animals than in unvaccinated ones The results obtained by Grundmann (1953) in experiments with staphylococci also suggest that the state of immunity of the animal may be of importance in the location of an infection

In the present experiments however vaccination had no certain effect on location of the infection to the skeleton

B DURATION OF SURVIVAL

In numerous investigations referred to in the two monographs Die BCG schutzimpfung (Griesbach 1954) and BCG vaccination (Rosenthal 1957) BCG vaccination has been found to prolong the survival of guineapigs superinfected with tubercle bacilli To achieve such prolongation however the

animals must be superinfected within a certain time after vaccination the dose of bacilli must not be too large and vaccination must be adequate This again underlines the necessity of standardised experiments The shorter survival of the unvaccinated animals is due to rapid development of tuberculosis in various extra skeletal organs In vaccinated animals the infection also occurs but runs a much slower course The histological and bacteriological findings in the present experiment were in accord with those described by previous workers

It is however remarkable that none of the unvaccinated animals in the present investigation died spontaneously This may be explained at least partly by the assumption that with the technique used a large proportion of the bacilli were not promptly transported away by the blood stream but were retained in the Spongostan The properties of the bacilli and the strain of animals used may also have been of importance In preliminary experiments (not described here) some of the unvaccinated animals died so that in the series the experiments were stopped after 4 months As mentioned previously the breed of animals was afterwards changed and the technique for culture of bacteria was modified

Since none of the animals died except a few in the preliminary experiments the method used satisfies the first of the three requirements set forth on page 11

C TUBERCULOSIS OF THE LEG OPERATED UPON

In many if not all of the experimental animals a tuberculous lesion developed at the site of inoculation in the bone It is not possible to say with certainty whether the animals killed after 1 week really would have developed lesions at the site of inoculation Neither is it known with certainty whether those animals killed at the end of the experimental periods in series II and III really had had skeletal tuberculosis But since it was possible to follow the growth and successive regression of the lesions in these two series and then to find that they were missing after a certain time it would appear justified to assume that also those animals killed last had had such foci This implies that the method described satisfied the last 2 requirements set forth in the introduction on page 11

It is well known that superinfection of a vaccinated animal with virulent tubercle bacilli may cause initially larger tuberculous lesions at the site of inoculation than corresponding infection of an unvaccinated animal (Griesbach 1954 Rosenthal 1957) The lesions however tend to regress in vaccinated animals but to progress in unvaccinated ones This tendency was also noted in the present investigation In bone preparations in series I gross abscesses did not appear at the site of inoculation until 5 weeks after deposition of the bacilli while in series II and III they appeared already within 2 weeks In series I the abscesses persisted throughout the experimental period (4 months) while in series II and III they began to regress alrea[illegible] be[illegible] at 5 weeks In series II these abscesses

healed completely within 4 months and in series III healing also appeared to progress in the same way though the end result in this series was uncertain since the animals were sacrificed after 4 months instead of after 6 months as in series II The experiments thus showed

firstly that the abscesses developed sooner in the vaccinated than in the un vaccinated animals and

secondly that the foci at the site of inoculation clearly tended to heal in the vaccinated animals while no such tendency was observed in the unvaccinated animals during the experimental period

In all three series the marrow in the operated leg showed miliary foci remote from the site of injection They persisted throughout the experimental period in series I and II but were no longer demonstrable after the 10th week in series III This difference was probably due to the differences in the vaccination procedures

D TUBERCULOSIS OUTSIDE THE OPERATED LEG

The unoperated femur and tissue specimens from the lungs liver and spleen were also studied histologically to estimate the spread and course of the infection elsewhere in the body In these regions it was sometimes not possible histologically to demonstrate or exclude the possibility of tuberculous foci with certainty be cause the histological picture was not unequivocal Sometimes the foci were seen at a very early stage when they consisted of only some tens of cells and then had no specific appearance These small foci were nevertheless regarded as being tuber culous because several of them contained acid fast rods culture gave growth of tubercle bacilli and in the liver and spleen the small foci gradually developed into large tuberculous lesions

Tubercle bacilli spread early to all of the organs examined In the bone marrow lungs liver and spleen disseminated foci appeared earlier in the vaccinated than in the unvaccinated animals In the latter such foci were first seen in animals examined 2 weeks after inoculation

In the unvaccinated group tuberculous foci were seen from then on in all the organs from the animals killed during the experimental period (4 months) On the other hand tuberculosis was often not demonstrable in the parts examined from specimens from the vaccinated animals Though tuberculosis might very well have been demonstrable in unexamined parts of these organs the results showed that vaccination had clearly retarded the development of tuberculosis

Since the purpose of the present investigation was to produce skeletal tuber culous lesions the findings in the contralateral unoperated femur were of parti cular interest None of the foci produced by haematogenous spread of the bacilli to the unoperated femur developed into large productive foci let alone abscesses during the experimental period

PART II

VII INTRODUCTION AND PURPOSE

It is well known that skeletal infections whether of tuberculous nature or not, are difficult to arrest or cure Experience has taught that such infections respond only slowly to antibiotics and that recurrences are common As far as tuberculosis is concerned this also holds for lesions outside the skeleton and can be explained in part by the nature of the tubercle bacillus But experience in the treatment of non tuberculous osteomyelitis strongly suggests that also the actual site of the lesions in the skeleton retard or prevent healing

The purpose of the investigation was to ascertain whether dihydrostreptomycin diffuses into the tuberculous abscesses described in Part I and if so how it is distributed there

Tuberculous skeletal lesions vary widely in structure and consist of areas of necrosis specific and non specific granulation tissue necrotic and newformed bone all in varying proportions As the initial link in an experimental investigation of the ability of anti tuberculous agents to diffuse into skeletal lesions however it was decided to avoid foci of complicated structure and instead study the tuberculous bone marrow abscesses of typical and simple structure *i e* of the typ described in Part I and readily reproducible in animals

VIII PREVIOUS INVESTIGATIONS

A INVESTIGATIONS WITH MICROBIOLOGICAL METHODS

Various researchers (Froyez and Froyez Roderer 1949 and 1952 Fellander et al 1952 Fellander 1955 Hever and Risko 1960 and Debeaumont 1966) who have used microbiological methods have tried to determine the concentration of streptomycin in tuberculous pus from patients with skeletal tuberculosis The results varied from patient to patient In some cases the concentration was so high that it had a clearly anti bacterial effect in others no streptomycin at all could be demonstrated No satisfactory explanation could be offered for this variation Froyez and Froyez Roederer (1949) discussed the possibility of the physico-chemical properties of the contents of the abscess being able to inhibit the antibacterial effect of streptomycin Hever and Risko (1960) found that abscesses that had existed for only a few months contained a larger amount of streptomycin than old chronic abscesses. The effect of a given antibiotic may

thus depend on the various properties of the abscess capsule and the varying composition of the debris in the necrotic lesion

Katayama et al (1954) who also used microbiological methods determined the streptomycin content of tuberculous skeletal abscesses 1 hour and a half after injection of half a gram of streptomycin into a patient and found that at a blood concentration of 8 2 μg/ml the pus contained 2 7 μg/ml the granulation tissue 0 53 μg/ml the fibrous tissue 0 37 μg/ml and caseous necrosis 0 32 μg/ml

B INVESTIGATIONS WITH AUTORADIOGRAPHY

No detailed autoradiographic investigations have apparently been published on the distribution of anti tuberculous drugs in tuberculous lesions

In an investigation of the distribution of dihydrostreptomycin in healthy tissues in mice Andre (1956) also studied a single intramuscular tuberculous abscess in one mouse Thirty minutes after injection of tritium labelled dihydrostreptomycin the abscess was removed for autoradiography No microautoradiograms were made but according to Andre (1956) the published autoradiogram showed the highest concentration of dihydrostreptomycin in the abscess capsule Inside the abscess th activity was highest in the periphery and only low centrally

Hanngren and Andre (1964) investigated the distribution of tritium labelled dihydrostreptomycin in tuberculous lesions in the lungs of guineapigs by means of whole organ autoradiograms They found that in the tuberculous foci of the lung the concentration was higher than in the normal lung tissue where the concentration however did not reach that of the blood Within the tuberculous lung cavities radioactivity was found only to a very little extent

Hanngren (1959) examined a few abscess s in the lungs chest and lymph nodes 15 and 30 minutes after injection of PAS labelled with ^{14}C and tritium He too found the concentration to be highest in the abscess capsule and to fall rapidly towards the centre of the lesion As in Andre s work (1956) he studied whole-organ autoradiograms but not microautoradiograms

IX CHOICE OF ANTIBIOTIC

Dihydrostreptomycin is no longer used clinically because it sometimes causes impairment of hearing Streptomycin is now generally used instead In the present investigation dihydrostreptomycin was nevertheless used for the following reasons

1) Tritium labelled dihydrostreptomycin is obtained by a catalytic hydration of streptomycin The procedure is simple and in this way it is possible to obtain a final product with a high specific activity without any laborious purification The method was devised and described by Andre (1956)

Tritium labelled streptomycin cannot be obtained with this simple method but only by more complicated procedures such as that described by Wilzbach (Wenzel and Schulze 1962 Advances in tracer methodology 1963) The products obtained by such procedures probably require extensive laborious purification Since these methods for lab lling streptomycin have apparently not been used before it is not known what specific activity and what degree of purity of the final product can be obtained

2) No substantial differences have been found between streptomycin and dihydrostreptomycin regarding their antibacterial effect or pharmacological properties such as the distribution of the two drugs in the body and their excretion appear to be similar (Donovick and Rake 1947 Edison et al 1948 Feldman et al 1948 Hobson et al 1948 Levin et al 1948 Rake et al 1948 Waksman 1949)

Certain small differences such as the fact that dihydrostreptomycin can injure hearing and streptomycin the sense of balance that dihydrostreptomycin is less inclined to produce allergic reactions (Hobson et al 1948) is presumably irrelevant to the present study

3) No convincing evidence has been produced that dihydrostreptomycin or streptomycin is broken down in the body (page 54)

X SYNTHESIS OF RADIOACTIVE DIHYDRO-STREPTOMYCIN

A CHOICE OF ISOTOPE

The beta particles of tritium have low energy E max 0 018 MeV and are therefore suitable for autoradiography where high resolution is desired With a suitable autoradiographic technique the isotope can be located at the cellular level which was desirable in the present investigation

Labelling of dihydrostreptomycin with tritium is technically easy and gives a pure final product with high specific activity (page 50)

Tritium is also a much cheaper isotope than ^{14}C which might also be used in such experiments

B PREPARATION OF RADIOACTIVE DIHYDROSTREPTOMYCIN

The radioactive dihydrostreptomycin was prepared at Isotoptjansten AB Atomenergi in Studsvik according to a modification of Andre s (1956) method *)

250 mg of streptomycin HCl 5 mg of platinum oxide 0 5 ml dimethylformamide and 0 075 ml distilled water were mixed in a 2 ml retort with a magnetic stirrer The retort was connected to one of the limbs of a tritiating apparatus according to Wenzel and Schulze (1962 page 22 Fig 13) in which 30 Ci tritium had been adsorbed on uranium in an ampoule connected to the other limb of the apparatus The reagent solution was cooled with liquid nitrogen and the apparatus was evacuated to 0 01 mm Hg After the mercury level had been raised in the gas buret and the manometer tube the uranium ampoule was heated to about 420 C at which the tritium evaporated and was collected in the buret At the same time the reaction vessel was allowed to recover room tempera ture

The volume of the tritium and the pressure were read on a calibrated scale after which the gas was allowed to enter the reaction vessel via a three way cock The free volume of the reaction vessel was calculated from re determination of the volume and pressure

*) This modification was devised by Nils Walde who also prepared the radioactive dihydrostreptomycin and composed this section

The solution was stirred vigorously and the tritiumabsorption was followed by the decreasing pressure and volume After the reaction had stopped the stirring was interrupted the final pressure and the final volume were read the reaction vessel was cooled as before and the remaining tritium gas was adsorbed on uranium The mercury level was lowered so that the residual gases could be pumped out

The reaction vessel was disconnected and the solution was filtered through Hyflo Supercel® The filter and the vessel were washed with water to a final volume of about 30 ml The water was removed by rotation evaporation at reduced pressure (20 mm Hg) The rest was dissolved in about 30 ml of water followed by re evaporation This was repeated twice The residue was dissolved in the smallest possible amount of methanol about 1 5 ml after which 9 ml acetone was quickly added with consequent precipitation of streptomycin and dihydrostreptomycin The solvent was removed through a dipping filter The precipitate was dried in a vacuum and the streptomycin mixture was dissolved and transferred to a 50 ml graduated flask

C ANALYSIS OF PREPARED DIHYDROSTREPTOMYCIN

The efficiency of the hydrogenation of streptomycin and the purity of the product were determined by the manufacturers according to the following description *)

The efficiency of the streptomycin hydrogenation was determined by analysing the tritium labelled product. The dihydrostreptomycin content was determined spectrophotometrically (Hiscox 1951) and the streptomycin content by an ultraviolet absorption method (Titus and Fried 1948) Two products were synthetized the first contained 72 1 % dihydrostreptomycin and 27 9 % streptomycin the second 81 4 % dihydrostreptomycin and 18 6 % streptomycin

Paper chromatography was done according to Winsten and Eigen (1948) In the development of the chromatograms equal volumes of the following solutions were mixed and used immediately

0 1 % diacethyl in water
20 % (w/v) KOH in water
2 5 % α naphtol in alcohol.

This mixture stained both the dihydrostreptomycin and the streptomycin The chromatogram was examined in a chromatograph scanner and the radioactivity was found only over the dihydrostreptomycin spots

The specific activity of the product was determined with the aid of a liquid scintillation spectrometer The activity of the first of the two products synthesized was 1 14 mCi mg that of the second 0 14 mCi/mg The low specific activity of the latter product was due to a technical mischance which stopped the reaction too early

The purity and stability of the products obtained were checked also by the author with paper chromatography which was done according to Ishida et al. (1953) A purified non radioactive dihydrostreptomycin in water solution was

*) See footnote page 51

used as reference substance for all chromatograms*) Pieces of the paper strips were punched out for microbiological control after which the development of the chromatograms was done with equal volumes of the following solutions

0 1 % diacetyl in water

1 % α naphtol in a solution of 8 % (w/v) NaOH in water

The solutions were used immediately after they had been mixed (Chromatographic and Electrophoretic Techniques 1960) Finally the strips were examined in a chromatograph scanner

The microbiologic control was carried out at the Bacteriological Institution Malmo General Hospital with the technique used for estimating the susceptibility to antibiotics (Eriksson 1960) A blood agar plate was covered with an even layer of staphylococcus albus of a strain which is very susceptible to dihydrostreptomycin but resistant to other antibiotics The punched out pieces of paper all of the same size were placed on the blood agar surface after which the plate was incubated at 37 C for 18 hours and then examined for inhibition zones around the pieces of paper

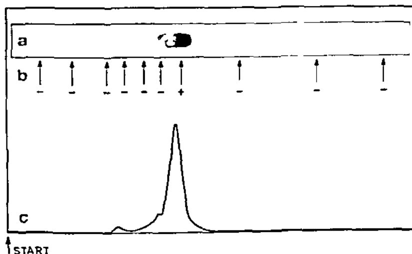


Fig 17

Occurrence of colour reaction antibiotic and radioactivity in paper chromatogram of the radioactive dihydrostreptomycin

\+ occurrence of inhibition zone in microbiological tests
— absence of inhibition zone in microbiological tests
a. chromatogram with spot
b arrows indicate segments of paper strip used for microbiological examination
c curve of radioactivity in chromatogram

The colour reaction the occurrence of radioactivity and the inhibition zones coincided in all the tests (Fig 17) The degree of purity of the product obtained thus appeared to be high.

*) The purified dihydrostreptomycin was courteously supplied by Leo Pharmaceutical Products Copenhagen.

XI STABILITY OF DIHYDROSTREPTOMYCIN IN THE BODY

Dihydrostreptomycin and streptomycin appear not to be broken down or, if so not appreciably in the body The bulk of dihydrostreptomycin given parenterally is excreted in the urine within 24 hours after the injection and no degradation products of the two substances have been found (Levin et al 1948 Rake et al 1948 Waksman 1949 Andre 1956 Goodman and Gilman 1965)

But since some researchers (Adcock and Hettig 1946 Giesen and Koelzer 1950) have found only about 60 % of streptomycin to be excreted in the urine in the present investigation the excretion was checked in cooperation with AB Kabi in 8 volunteers The urinary excretion of tritium labelled dihydrostreptomycin in guineapigs was also studied

1) Each of the volunteers received an injection of 1 ampin containing 1 030 grams of dihydrostreptomycin sulphate intramuscularly Three of them excreted 0 84 0 87 and 0 98 grams within the first 10 hours Four others excreted 0 81 0 89 0 91 and 0 94 grams respectively in the first 24 hours The eighth excreted 0 972 0 016 and 0 006 grams during the first 3 days thus all together 0 994 grams It should be observed that according to AB Kabi injection of one ampine means injection of only 0 960—0 980 grams

Urine analysis was done with the microbiological method used routinely by Kabi (Grove and Randall 1955) To check this method the urine content of one of the patients was studied with a spectrophotometric (Hiscox 1951) and a colorimetric method (Monastero 1952) Good agreement was found between the results of the microbiological method and those of the other two methods

2) Three guineapigs were given 1 5 7 and 7 mCi tritium labelled dihydrostreptomycin intracardially The animals were killed 30 minutes 1 hour and 4 hours later by intraperitoneal injection of mebumal and the urinary bladder was punctured immediately Since the urine was very cloudy it was centrifuged and the clear supernatant was pipetted off and subjected to paper chromatography (page 52) after which the chromatogram was examined in a chromatograph scanner A curve of the type shown in Fig 18 was obtained for each of the animals

The radioactivity was divided into two separate peaks When stained and studied microbiologically (page 53) the colour reactions and the inhibition zones were found to correspond to these peaks which argues strongly against any degradation of the dihydrostreptomycin

To find out why dihydrostreptomycin in guineapig urine is divided into two fractions on paper chromatography urine was taken from 2 guineapigs that had received an intracardial injection of 1 ml of an aqueous solution containing 10 mg non radioactive dihydrostreptomycin/ml The animals were killed 3 hours after

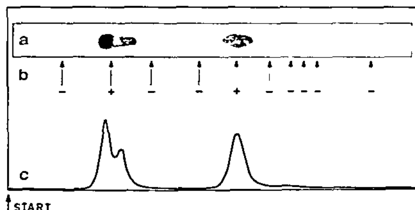


Fig 18
O currence of colour reaction antibiotic and radioactivity in paper chromatogram of guineapig urine

+ occurrence of inhibition zone in microbiological tests
— absence of inhibition zone in microbiological tests
a chromatogram with spots
b arrows indicate segments of paper strip used for microbiolo ical examination
c curve of rad oactivity in chromatogram

the injection the urinary bladder was punctured and the urine was collected A third of the urine was acidified to pH 1 with hydrochloric acid and a third was treated with β glucuronidase (Ketodas ® manufactured by Warner Chil kott) Th urine was allowed to stand at room temperature over night after which pap r chromatography was done on both untreated acidified and enzyme treated urine The untreated urine showed the usual distribution in two fractions while in the acidified urine and the urine treated with enzyme the more rapidly migrating spot had disapp ared while the slow one was seen at the same site as before

Comment Th guineapig exp rim nts revealed nothing suggesting that the dihydrostreptomycin is metabolised Judging from the above investigation the separation of the dihydrostreptomycin into two fractions on paper chromato graphy of the urine can be explained by part of the dihydrostreptomycin being bound to glucuronic acid and changing its rate of migration No such separation occurred after acid hydrolysis or treatment of the urine with glucuronidase

XII AUTORADIOGRAPHIC TECHNIQUE

A CHOICE OF AUTORADIOGRAPHIC EMULSION

Emulsion Ilford G 5 was used It was supplied attached to glass slides 1'X3' To decrease background blackening the thinnest available emulsion layer was selected namely 10 μ

Comment Since both the specific activity and the amount of the tritium labelled dihydrostreptomycin was smaller than expected (page 52) it was necessary to use such a sensitive film emulsion as Ilford G 5, even though the employment of such an emulsion results in high background blackening According to the manufacturers the emulsion is sensitive to all charged particles of any energy

Since it was thought that the background blackening with this emulsion might disturb identification of the dihydrostreptomycin at the cellular level for micro autoradiography use was also made of emulsion Ilford K 2 which is recommended by the manufacturers for tritium studies where high resolution is desired Because of the relatively low sensitivity of this emulsion background blackening will be less But the K 2 emulsion proved of no value in this experiment because of its low sensitivity

Since the soft radiation of tritium only reaches about one μ into the film emulsion (Levi 1964) a thin emulsion layer could be used because it helps to decrease background blackening

B HISTOLOGICAL METHODS

In autoradiography of a substance such as dihydrostreptomycin which is water-soluble the ordinary histological technique cannot be used because then the substance is dissolved from its original site in the tissue Freeze drying has therefore been recommended for such work by Holt et al (1949) Harris et al (1950), and Winteringham et al (1950)

1 *Freeze drying and sectioning of whole guineapig femur with tuberculous abscesses*

Since the guineapig femur could not be decalcified for the above reasons and since it has a thick and hard corticalis which splits and markedly deforms histological sections cut in the usual way a method devised by Ullberg (1954) for sectioning in a coldroom was used

After injection of isotope the animal was killed (page 61) the femur with the tuberculous abscess was removed and frozen immediately in hexane and carbon

dioxide snow It was then transferred to a coldroom with a temperature of —15° C and embedded in a mixture of carboxymethyl cellulose and water and frozen on a synthetic fibre block The preparation was sectioned in the coldroom with a Leitz sliding microtome The sections which were about 15 μ thick were caught on a strip of adhesive tape and allowed to dry in the coldroom for at least 12 hours.

In order to prevent condensed water from moistening the sections when they were taken out of the coldroom they were placed in an airtight box with a Petri dish containing phosphorous pentoxide They were then taken out of the coldroom while still in the box which was not opened until it had assumed room temperature

2 *Freeze drying and sectioning of small m[illegible] p[illegible]cimens with tuberculous abscess[illegible]*

The animals were killed and the femur with tuberculous abscesses was removed immediately The proximal fourth of the bone wa[illegible] [illegible]ut off with scissors This caused longitudinal cracks in the corticalis down towards the distal end of the bone and half of the corticalis could therefore be removed without any appreciable damage to the bone marrow With a sharp pointed knife the bone marrow was then removed from the remaining corticalis and divided into pieces 4—5 mm long and frozen immediately in a mixture of hexane and carbon dioxide snow The interval between the death of the animal and the deposition of the pieces into the mixture was as a rule 2—3 minutes The pieces were then freeze dried for 1 week in a freeze dryer (Edwards Tissue Dr[illegible]r T D 2) They were afterwards embedded in paraffin in the usual way and stored at 20 C until sectioned Sectioning was done at room temperature but to avoid the sections from coming into contact with water they were also caught on tape according to the method of Ullberg (1954)

Comment Since the microscopical picture of the bone marrow and the tuberculous tissue was largely destroyed by sectioning and drying in the coldroom (page 56) this method could not be used for preparing microautoradiograms Instead the method described above was used

Th[illegible] sp[illegible]cimens were freeze dried for 1 week This was presumably unnecessarily long (Andre 1956 Hanngren 1959) but was nevertheless used because the experimental conditions provided no possibility of finding out which time was the most suitable

C EXPOSURE DEVELOPMENT AND FIXING OF WHOLE FEMUR AUTORADIOGRAMS

The autoradiographic plates were exposed according to the technique described by *inter alia* Ullberg (1954) and Andre (1956) The freeze dried taped sections

were stuck to the photog aphic emulsion in the darkroom A piece of paper folded a few times, was placed on the tap in order to secure an even pressure against the emulsion 3—4 plates with such pap r were placed in a press between a pair of plywood pl tes and wrapped in opaque paper after which a pair of paper clips er placed outside the package as a press The films were then exposed in a freeze box at 20 — 25° C Before development the tape with the adherent secti n w refully loosened from the emulsion the film was developed 5 minu tes X ray developer G 230 rinsed for 1 minute in water and fixed 15 rt X ray fixer G 305 after which it was rinsed in water for 5 in the air

I PE DEVELOPMENT AND FIXING OF THE 1ALL SPECIMEN AUTORADIOGRAMS

ological sections were fastened to the autoradiographic vere dipped in a mixture of 12 % pure glycerin and 88 % rd then allowed to dry for 10—15 minutes (Hammarstrom

able to apply several autoradiograms to the same plate, a piece of stiff the ize of the autoradiographic plate was cut An equally large piece of tape adhesive on both sides was fastened to the paper Pieces of tape with the histological sections attached were trimmed and fastened to the collecting tape The pieces of paper with the adherent tape and histological sections could then be readily fastened in the dark to the film emulsion treated with glycerin alcohol (Andre 1956 Hanngren 1959) As in autoradiography of sections from whole guineapig femora the sections and the photographic plates were placed in a press and exposed at an ambient temperature of -20 — 25° C Before they were developed they were placed in xylol for 10—12 hours which loosened the paper and the tape from the plate and section They were then passed through an alcohol series 2 minutes in absolute alcohol 2 minutes in 96 % alcohol and 2 minutes in distilled water They were developed 5 minutes in Gevaert X ray developer G 230 rinsed for 1 minute in water and fixed 5 minutes in Gevaert X ray fixer G 305 and then placed for 15 minutes in distilled water

Comment In this investigation use was made of a technique according to which the tape strip with the histological section is fastened to the photographic emulsion after the exposure the tape is loosened but the histological section is left in position on the emulsion during development fixation staining and mounting In this way a preparation is obtained where the histological section remains on the autoradiogram it has itself produced Such a preparation gives the examiner the opportunity to identify the radioactive substance at the cellular level One difficulty is that the section must not be dislocated from its original position

if this identification is to be possible The conventional method described by Pelc (1947) with stripping film where the section is fastened between the slide and the film emulsion could not be used for such a water soluble substance as di hydrostreptomycin Instead a method described by Andre (1956) and modified by Hammarstrom et al (1965) was used According to this modification the emulsion surface is pretreated with glycerin and absolute alcohol so that the sec tion will adhere to it If the film is not pretreated the section is apt to fall off when being developed fixed and stained but since the radiation energy of tritium is so weak the layer interposed between the film emulsion and the tissue layer must be very thin Otherwise the radiation will be absorbed by the interposed layer The alcohol evaporates and the glycerin is absorbed by the film emulsion but the surface is then sticky and the section adheres to the surface of the emulsion

E STAINING AND MOUNTING

After the tape strips with whole femur sections were loosened from the film emulsion the sections were stained according to van Gieson and mounted on slides in Euparal Attempts were made to stain the sections with haematoxylin eosin but the bone marrow was stained so unevenly that this staining method could not be used

The small bone marrow sections attached to the developed autoradiograms tended to fall off during the staining procedure They were therefore held vertical during the staining procedure and the various solutions were slowly added with a pipett to one edge of the plate The following staining method proved to give the best results Mayer s haematoxylin 10 minutes distilled water 10 minutes 70 % alcohol 1 minute 96 % alcohol 1 minute absolute alcohol 1 minute and xylol 1 minute After staining the sections were mounted in Euparal

F DISADVANTAGES OF THE METHODS

The methods described in the sections B—E have certain disadvantages which make themselves fell particularly in the study of bone marrow because of the structure of this tissue The same methods was also tried on lung liver and spleen tissue but then none of these disadvantages proved so disturbing

The finer histological structure of the bone marrow in the freeze dried stained whole femur sections was distorted into a coarse network in which the individual

cells could barely be distinguished The marrow in this sections cannot be studied under higher magnification than about 5—10 times

A large part of the small freeze dried specimens loosen or become displaced from their original positions on *the film emulsion during the procedures described* on pages 58—59 In addition the marrow often contracts in relation to the film emulsion which can be observed on the narrow margin of blackening sometimes seen in the autoradiogram outside and around the histological section The relation of the section to the rest of the autoradiogram shows that lateral displacement or diffusion of isotope cannot have caused this border In the evaluation of the autoradiogram preparations or part of preparations must be used where no such contraction has occurred

G HISTOCHEMOGRAMS

Bone marrow as well as other tissues can sometimes blacken a photographic emulsion even in the absence of radioactive substances (Boyd and Board 1949, Boyd 1955)

To ascertain whether any such artefact had occurred on the autoradiograms four guineapig femora with tuberculous abscesses were treated in exactly the same way as those used for whole femur autoradiography the only difference being that the animals had not been given dihydrostreptomycin The taped sections were placed on autoradiographic plates with Ilford G 5 emulsion The plates were exposed for 6 months and developed and fixed No blackening due to the tissue sections was observed

Four tuberculous bone marrow abscesses were removed and treated in exactly the same way as those used for microautoradiography and the animals had not been given dihydrostreptomycin The taped sections were placed on plates with Ilford G 5 emulsion which were exposed for 3 months after which the film and the tissue sections were treated in the way described on page 58 No blackening due to the tissue sections was seen here either

XIII STUDIES OF THE DISTRIBUTION OF DIHYDRO STREPTOMYCIN IN THE TUBERCULOUS ABSCESS

A MATERIAL

In a series of unvaccinated guineapigs tubercle bacilli were inoculated into one of the femora according to the m thod described in Part I After 2—4 months by which time abscesses had certainly developed in the bone marrow cavity animals weighing about 500 grams were selected for injection of tritium labelled dihydrostreptomycin The experiment is described below

1 *Whole femur autoradiography*

S ven animals were each given 3 mCi of tritium labelled dihydrostreptomycin corresponding to 6 μCi p r gram bodyweight intracardially Before the injection non radioactive dihydrostreptomycin was added as carrier substance so that the total amount of dihydrostreptomycin was about 11 mg dihydrostreptomycin p r animal The animals were killed by a blow against the neck one ½ hour two 1 hour two 2 hours and two 4 hours after the injection The femur with the tuberculous abscess was removed immediately and placed in a mixture of hexane and carbon dioxide snow The bone was then sectioned and autoradiograms pre pared in the way described on pages 56—59 The plates were exposed for about 6 months

Comment Since autoradiography of whole bones was thought to require a longer exposure time than microautoradiography the animals received twice the dose given to those used for microautoradiography The dose of 11 mg dihydro streptomycin p r animal corresponds roughly to a dose of 1 5 gram for human beings It would have been desirable to use only labelled dihydrostreptomycin and then in a dose corresponding to 2 grams for human beings in order to reduce the exposure time to a minimum but this was not possible because the radioactive substance would then not have been enough for the investigation

2 *Microautoradiography*

Thirteen animals were used for microautoradiography of the tuberculous abscesses Each was given 1 5 mCi tritium labelled dihydrostreptomycin intracar dially *i e* 3 μCi per gram bodyweight Also here non radioactive dihydrostrepto mycin was added so that the dose should correspond to about 11 mg dihydro streptomycin per animal The animals were killed by a blow against the neck four animals ½ hour three 1 hour three 2 hours two 4 hours and one 5 hours after the injection The tuberculous abscesses were then removed freeze dried and sectioned by the method described on pages 57—59 The plates were exposed for about 3 months

Half an hour after the injection the whole femur autoradiograms showed a high concentration of radioactivity in the periphery of the tuberculous abscess and less in its centre (Fig 19)



Fig 19
Whole femur autoradiogram half an hour after injection of dihydrostreptomycin ×2

The microautoradiograms showed a marked concentration in the peripheral part of the central necrosis (Figs 20 and 21) where the blackening of the autoradiogram was much stronger than over the surrounding normal marrow, the outermost non necrotic layer of the abscess and over the innermost part of the necrosis



Fig 20
Microautoradiogram half an hour after injection of dihydrostreptomycin ×15



Fig 21
Histological section of same lesion as shown in Fig 20 Htx eosin ×15

After *1 hour* the blackening on the whole femur autoradiograms over the abscess was relatively even stronger than after half an hour compared with that over normal marrow and musculature It was however weaker than over the periosteum and epiphyseal line (Fig 22)

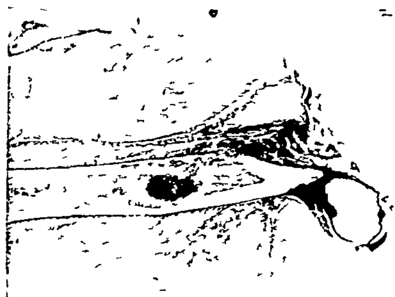


Fig 22
Whole femur autoradiogram 1 hour after injection of dihydrostreptomycin ×3

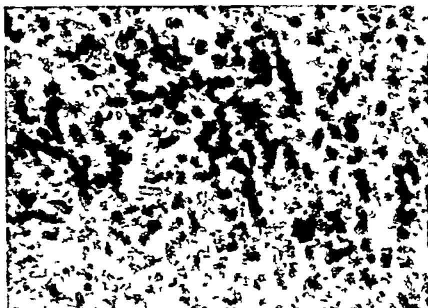


Fig 31
Microautoradiogram of normal marrow 5 hours after injection of dihydrostreptomycin. ×670

The blackening over the necrosis was localised especially to areas with nucl ar remnants and was much weaker over intermediate areas (Figs 32—37)

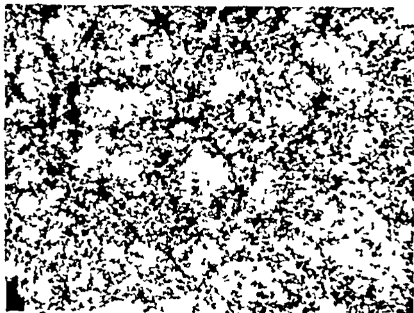


Fig 32
Microautoradiogram of necrosis 5 hours after injection of dihydrostreptomycin Blackening strongest over areas with nuclear remnants and weakest over intermed ate areas ×260

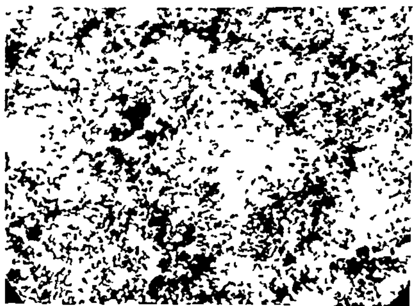


Fig 33
Detail of area in Fig 32 ×670

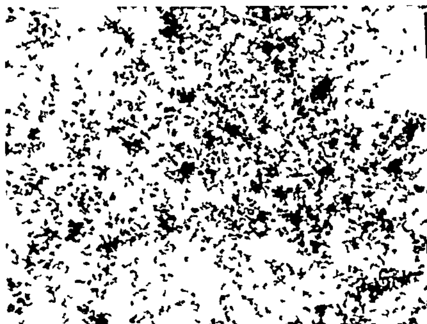


Fig 34
Microautoradiogram of necrosis 5 hours after injection of dihydrostreptomycin Micro scope focused on silver granules ×670

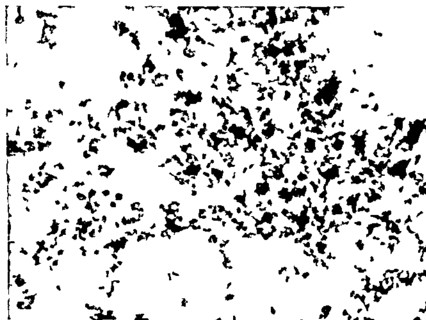


Fig 35
Same area as in Fig 34 Microscope focused on nuclear remnants ×670

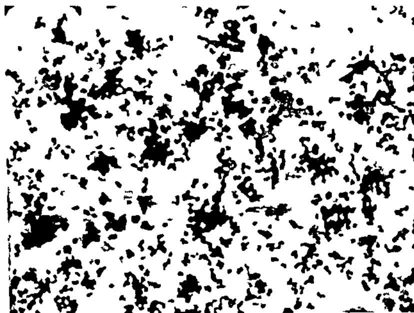


Fig 36
Microautoradiogram of necrosis 5 hours after injection of dihydrostreptomycin Microscope focused on silver granules ×1300



Fig 37
Same area as in Fig 36 Microscopic focused on nuclear remnants ×1300

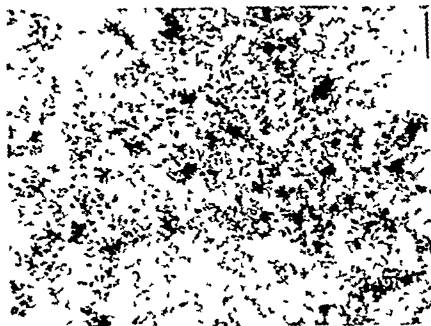


Fig 34
Microautoradiogram of necrosis 5 hours after injection of dihydrostreptomycin Microscope focused on silver granules ×670

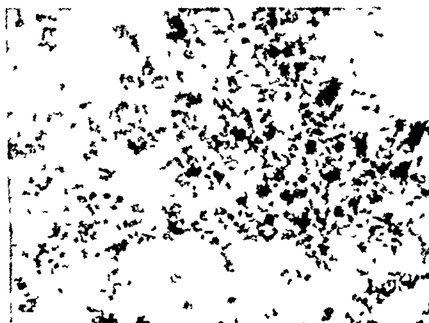


Fig 35
Same area as in Fig 34 Microscope focused on nuclear remnants ×670

the concentration of the antibiotic in th bits of tissue This experiment shows that further investigation is necessary to check whether the radioactive substance in the necrotic region of the abscesses consists entirely or partly of active and/or inactive dihydrostreptomycin and/or degradation products

XV DISCUSSION

A WHOLE FEMUR AUTORADIOGRAMS

Since the middle of the tub rculous abscess is necrotic and does not contain any blood vessels one might expect the concentration of dihydrostreptomycin to be lower there than in surrouding tissues Research on patients has however shown that streptomycin can diffuse into necrotic parts of the tuberculous abscesses in the skeleton (page 48) But the difference between these investigations and the experimental ones discussed below are so large that no comparisons can be made with our present knowledge of the problem

Andre (1956) found the activity to be highest in the capsule rapidly to de crease towards the centre of the abscess This seems to suggest that dihydro streptomycin diffuses into a necrotic abscess only to a small extent Hanngren s *(1959) observations on the diffusion of para aminosalicylic acid in tuberculous* abscesses app ars to argue in the same direction

In the present investigation however the dihydrostreptomycin seems to have a sp cial and unexpected affinity for the necrotic centre of the abscess On the other hand th^ blackening over both the outermost non specific granulation tissue layer and the inner specific tissue layer was only slightly stronger than that over normal marrow The difference in the results can probably be explained by the fact that Andre (1956) stopped his investigation already half an hour after the injection of the radioactive dihydrostreptomycin while in the present investiga *tion the exp riment was continued up to 5 hours after th injection Differences* in the size of the abscesses and their structure as well as the composition of the necrotic material may p rhaps also be of importance

The autoradiograms illustrated in Figs 19 and 20 show the distribution of the blackening in abscesses half an hour after the injection The blackening is seen in the periphery of the abscesses as in Andre s (1956) autoradiogram In the preparations removed later however the radioactive substance had diffused into the entire necrotic centre and the concentration there was much higher than in surrounding normal marrow up to 4 hours after the injection The di hydrostreptomycin thus appears to have concentrated in the actual necrotic substance

B MICROAUTORADIOGRAMS

The microautoradiograms showed that the blackening over the necrotic parts was invariably concentrated over parts of cells or remnants of cells that had taken on nuclear stain It was not possible to decide exactly over what sort of tissue this labelling was located because the tissue was necrotic which makes identification difficult and because the preparation was somewhat blurred But this labelling pattern was not seen over areas void of nuclear remnants (Figs 30—37) In many of the preparations the blackening over the necrosis was so intense that it obscured the tissue But since sections had also been taken simultaneously for histological preparations it was known that the blackening had occurred over the necrotic areas

No explanation can be offered for this pattern of distribution of the radioactivity The radioactive substance obviously diffused into the necrotic tissue and concentrated there Whether the substance really consisted of active dihydrostreptomycin or entirely or partly of inactive dihydrostreptomycin bound to one of the components of necrotic substance as suggested by Froyez and Froyez Roederer (1952) (page 48) or a degradation product is not known

If the dihydrostreptomycin (or streptomycin as in Froyez investigation) is bound to any of the components of the necrosis and thereby inactivated, this may explain the accumulation in the autoradiogram as well as the discrepancies between the results obtained when the streptomycin content in tuberculous pus was determined by microbiological methods.

The high activity found by Andre (1956) over the abscess capsule could not be verified by microautoradiography in this investigation It was found that the blackening was considerably weaker over both the normal bone marrow and the non specific and specific granulation tissue of the abscess than over the necrosis. The blackening was mainly diffusely spread over all three layers In some of the preparations the degree of blackening was the same over all three while in others the blackening was slightly stronger over the specific tissue layer than over the other two A possible explanation why Andre (1956) believed to find a higher activity over the abscess capsule may be that the fine histological details in his autoradiogram were difficult to interpret and that the activity was in reality confined to the outer layer of the necrosis i e the layer immediately inside the wall of the abscess

SUMMARY

Part I

A method is described for inducing a progressing local tuberculous lesion of the skeleton of the guineapig

According to this method a piece of Spongostan impregnated with a suspension of human tubercle bacilli is inserted in the marrow cavity through a hole drilled in the distal part of the femur of unvaccinated and vaccinated guineapigs

Vaccination proved to influence the development and healing of the lesions induced In the unvaccinated animals productive foci appeared after 2 weeks and these foci developed after about 5 weeks into abscesses which persisted until the end of the experiment (4 months) In the two series of vaccinated animals abscesses appeared already after 2 weeks After 5 weeks they began to diminish and all of them healed within 4 months

The method filled three requirements set up
no premature deaths almost regular development of a lesion and production of the lesion at a predetermined site

Part II

Tritium labelled dihydrostreptomycin was injected into guineapigs with tuberculous skeletal abscesses The penetration of the dihydrostreptomycin into and its distribution in the abscesses was studied on autoradiograms made with a freeze drying technique It was found that the dihydrostreptomycin penetrated the whole abscess and was especially concentrated in the necrosis where the concentration was considerably greater than in the wall of the abscess and in the normal bone marrow

On microautoradiograms it was seen that the dihydrostreptomycin was concentrated to cell remnants that had taken on nuclear stain

The possibility that the blackening of the autoradiograms or parts of them was due to radioactive metabolites of dihydrostreptomycin is discussed

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JORGE O GALANTE

TENSILE PROPERTIES OF THE HUMAN LUMBAR ANNULUS FIBROSUS

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TENSILE PROPERTIES OF THE HUMAN LUMBAR ANNULUS FIBROSUS

BY

JORGE O GALANTE

MUNKSGAARD
Copenhagen 1967

ORSTADIUS BOKTRYCKERI AB
GÖTEBORG 196[illegible]

To my wife
and my parents

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I INTRODUCTION

Motion in the vertebral joint complex occurs as a function of deformations in the intervertebral disc The magnitude of these deformations determines the extent of vertebral excursion When degenerative changes appear in the disc it is possible to demonstrate abnormalities in this mechanical response In terms of magnitude however severe structural changes cause only insignificant disturbances in functional behavior For that reason it is difficult to correlate symptoms arising from the lumbar spine with alterations in the load response of the intervertebral discs

The annulus fibrosus is an essential constituent of the fibrous intervertebral joint Its collagen fibers resist forces and provide most of the stability necessary during motions of the vertebrae Ruptures of the annulus a prerequisite of nuclear prolapse are common in disc degeneration Their occurrence can be the result of changes in the physical properties of the material with a decrease in the tensile strength of the fibers They can also be the product of alterations in the distribution of forces leading to local concentrations of stress Nerve endings have been reported in the most peripheral layers of the annulus (Fick 1904 Wiberg 1949 Hirsch Ingelmark and Miller 1963 Jackson Winkelman and Bickel 1966) pointing to a link between abnormal disc behavior and low back pain

The load deformation properties of the annulus fibrosus and particularly its response to tensile forces are evidently important determinants in the normal and pathologic function of the intervertebral disc The present study was set to answer specific questions brought forward by these considerations

1) What is the response of the lumbar annulus fibrosus to tensile forces and how is it related to the fiber framework?

2) Is this behavior uniform or does it vary in different areas of the annulus?

3) What is the tensile strength of the tissue?

4) How are these characteristics affected by age?

5) Do morphological or biochemical changes in the tissue due to degeneration processes affect its load extension response?

The present investigation

In this investigation the tensile properties of the lumbar annulus fibrosus were studied in human postmortem specimens

As a primary step the variables incident to the method of preparation and testing had to be controlled Changes induced in the water content of the samples

were thought to be of primary importance An attempt was made to control this source of variation and the first series of experiments approached this problem The methodology was further completed in regard to the ectioning and testing of the amples

After defining the in vitro laboratory conditions a tudy of tensile properties of the lumbar annulus fibrosus was made in relation to 1) Orientation of fibers 2) Location of samples in different area 3) Time dependent effects 4) Ten ile strength 5) Influence of age and degeneration morphological and biochemical correlations were u ed to evaluate these effect

The findings are di cu sed in the general context of the mechanics of the intervertebral disc

Morphological considerations

The normal disc

The intervertebral disc consists of three parts the annulus fibrosus in the periphery the cartilage plates above and below and the nucleus pulposus in the center

The annulus fibrosus in the adult lumbar spine is formed by a series of concentric encircling lamellae (Fick 1901 Beadle 1931) It is thicker anteriorly where the lamellae are more numerous than posteriorly Towards the sides the lamellae spread over a far wider area The peripheral lamellae attach themselves to the bony edge of the vertebral body in the manner of Sharpey fibers (Erdheim 1931) while the remaining continue into the cartilaginous plates (Fick 1901 Beadle 1931 Hirsch and Schajowicz 1952) In the front intimate connections exist with the anterior longitudinal ligament while the posterior longitudinal ligament is not so firmly attached to the annulus (Beadle 1931 Hirsch and Schajowicz 1952)

The collagen fibers run a uniform course in each lamellae the fibers of adjoining lamellae cross each other in opposite directions (Fick 1901 Strasser 1908—13) The annulus is basophilic a property which increases towards the nucleus The more superficial layers stain acidophilic as do the longitudinal ligaments Here the round cartilage like cells disappear and fibrocytes are encountered The fibers are thinner and less aggregated towards the midline and in the posterior area (Fick 1901 Hirsch and Schajowicz 1952) the amount of amorphous ground substance is greater here The hyaline cartilage endplates delimit the disc from the vertebral body above and below peripherally they come in contact with the bony epiphyseal ring (Beadle 1931)

The nucleus pulposus centrally situated consists of a three dimensional network of collagen fibrils enmeshed in a mucoprotein gel (Hirsch Paulson Sylven and Snellman 1952) It occupies about 30—50 per cent of the disc s cross section area (Perey 1957 Nachemson 1960 Eie 1966)

Changes induced by age and degeneration

During adult life the intervertebral disc undergoes a series of morphological changes of varying severity Beadle (1931) remarks that after the middle

were thought to be of primary importance An attempt was made to control this source of variation and the first series of experiments approached this problem The methodology was further completed in regard to the sectioning and testing of the samples

After defining the in vitro laboratory conditions a study of tensile properties of the lumbar annulus fibrosus was made in relation to 1) Orientation of fibers 2) Location of samples in different areas 3) Time dependent effects 4) Tensile strength 5) Influence of age and degeneration morphological and biochemical correlations were used to evaluate these effect

The findings are discussed in the general context of the mechanics of the intervertebral disc

sulfate was evident (Sylven 1951 Malinsky 1958) and identified by Orr (1954) as chondroitin 6-sulfate or chondroitin sulfate C

Kerato-sulfate was shown in the nucleus (Gardell and Rastgeldi 1954) and later hyaluronic acid and chondroitin sulfate A and C were demonstrated (Hall Lloyd Happey Horton and Naylor 1957 Bernardi Happey and Naylor 1957) Sulfur and dry weight determinations in human nuclei pulposi indicated that the polysaccharides remained at a stationary level or slightly decreased with age A large decrease in sulfur values was evident with gross degeneration (Hirsch Paulson Sylven and Snellman 1952) Sulfated acid mucopolysaccharides in the annulus fibrosus (Malinsky 1958) increased with age and accumulated in the clefts apparent in the structure with degeneration Non sulfated acid mucopolysaccharides decreased with age Similar changes occurred in the nucleus pulposus

An increase in the ratio keratosulfate — chondroitin sulfate of the nucleus pulposus with age was concluded by Hallen (1958) and Gardell and Hansen (1959) from hexosamine and sulfate determinations According to Hallen (1958) total hexosamine content decreased with age from 14 per cent of dry weight at 15 years to 6 per cent at 90 years

Findings of similar nature were evident in herniated disc material (Davidson and Woodhall 1959) the total polysaccharide content was reduced and the collagen content increased The chondroitin sulfate moiety of the polysaccharide fraction was reduced to a larger extent than the keratosulfate In degenerated discs the polysaccharide content was lower than in normal samples of the same age group (Naylor 1962)

Mitchell Hendry and Billewicz (1961) reported that the highest polysaccharide levels were reached in the 30—40 age group declining to its lowest values in later years Concomitantly with the increase in hexosamines slightly higher values of collagen were observed The nitrogen content was constant In prolapsed discs the hexosamines were decreased collagen and total protein were elevated No separation between annulus and nucleus was made in this investigation

In rabbits Hansen and Ullberg (1960) examined the uptake of S^{35} by the nucleus pulposus and found that cell uptake indicating chondroitin sulfate synthesis was highest at the annulus — nucleus junction With age this activity decreased

Buddecke and Sziegoleit (1964) identified chondroitin 4 sulfate chondroitin 6-sulfate keratosulfate and hyaluronic acid from human intervertebral discs The total content of these acid mucopolysaccharides decreased with age In newborn infants chondroitin sulfate constituted over 80 per cent of the acid mucopolysaccharides It decreased progressively while keratosulfate increased Between one and four years of age the chondroitin-4 sulfate / chondroitin 6 sulfate

ratio was 2 to 1 At 60 to 80 years of age chondroitin 6-sulfate was the main component of this fraction

In fractionation studies of glycosaminoglycan of the human nucleus pulposus (Antonopoulos 1965) a decrease with age in total content of glyco aminoglycan and chondroitin 6-sulfate was found Keratosulfate and hyaluronic acid remained constant

All of these investigations have approached the study of the intervertebral disc as a whole or have isolated the nucleus pulposus No analytical data is available on the changes exhibited by the annulus fibrosus

Differential thermal analysis studies (Dickson 1966) have shown that the peak temperature of both nuclear and annular samples was higher in young (below 10 years) than in older specimens (above 50 years) Samples of annular tissue obtained at surgery tended to shrink slightly below the expected values for postmortem tissue

The mechanical response of the disc and its alterations

Most experiments concerned with the mechanical response of intervertebral discs have been performed on segments of the spine including at least two vertebrae or part of them and the intervening discs (Fessler cit by Fick 1911 Göcke 1932, Petter 1933 Hirsch 1951 Virgin 1951 Ingelmark and Ekholm 1952, Hirsch and Nachemson 1954 Hirsch 1955 Bartelink 1957 Perey 1957 Brown Hansen and Yorra 1957 Hardy Lissner Webster and Gurdjian 1958 Evans and Lissner 1959 Nachemson 1960 Fie 1966 Rolander 1966) The specimens were placed between the jaws of a loading machine and were subjected to compression The load deformation curves obtained when plotting the results were convex to the deformation axis at moderate stress level as the load rose the rigidity of the specimen increased until a yield point was reached (Göcke 1932, Virgin 1951 Ingelmark and Ekholm 1952, Hirsch and Nachemson 1954 Brown Hansen and Yorra 1957 Rolander 1966) On removal of the load Göcke (1932) showed the presence of residual deformation its magnitude depending on the load reached and the age of the specimen Residual deformation was larger in young samples and after swelling in 0.9 per cent NaCl solution When performing load cycles hysteresis and residual deformation were evident (Virgin 1951 Ingelmark and Ekholm 1952, Hirsch and Nachemson 1954 Brown Hansen and Yorra 1957 Rolander 1966) Both phenomena were larger in the first cycle than in the following ones

Discs from old subjects exhibited greater stiffness and decreased residual deformation than young specimens (Göcke 1932 Virgin 1951) Hysteresis was

larger in the young material (Virgin 1951) Decreased compressibility in old discs was also shown by Ingelmark and Ekholm (1952) Hirsch (1951) used an elastometer to determine pressures in the outer surface of the annulus In degenerated discs considerable variations were found in pressure distribution

Hirsch and Nachemson (1954) measured the anterior and posterior expansions of the annulus fibrosus when compressing intervertebral discs and reported average figures of 0 5 mm expansion for 50 kg load and 0 75 mm for 100 kg loads Degenerated discs exhibited 30 per cent more expansion than normal ones Horton (1958) Naylor (1962) believed that the deformation characteristics of the annulus its elasticity were related to changes in the angle between alternating sheets of fibers This property showed no changes with age Horton (1958) calculated that the expansion values reported by Hirsch and Nachemson (1954) indicated a change of interstriation angle of 1° Brown Hansen and Yorra (1957) reported that the expansion of the annulus varied in different areas of the disc periphery

Intradiscal pressures (Nachemson 1960) in normal autopsy specimens were found to be on the average 30 to 50 per cent higher than the applied load per unit area Hydrostatic behavior of the nucleus was reported It was concluded that the nucleus pulposus transformed the vertical compressive forces into tangential stresses in the annulus fibrosus These stresses were estimated to be three to five times the applied load per unit area The vertical pressures on the annulus were thought to be low The weight bearing capacity of the posterior joints and ligamentous structures was found to be minimal at least for loads up to 220 Kp (Nachemson 1963) In degenerated discs the nucleus did not show hydrostatic behavior In general the pressures were lower than in normal discs It was concluded that the annulus was subjected to higher vertical stresses and lower tangential forces in degenerated specimens These findings were confirmed in intravital measurements (Nachemson 1966)

In the compression experiments previously discussed vertical displacements were measured between the jaws of the loading machines Rolander (1966) during motion studies of vertebral segments used direct extensometer readings He reported in normal discs values of vertical displacement of 2 6 per cent at 0 05 to 0 06 Kp/mm² load the previous investigators obtained corresponding values of 10 to 15 per cent displacement for the same loads The differences could be accounted for mainly by deformations in the vertebrae at higher stress levels In the same investigation (Rolander 1966) removal of the intervertebral joints and posterior ligaments did not lead to any increase in the range of movement severance of the ligament flava had a small effect the annulus fibrosus was found to be the main stabilizing factor in the vertebral segment With excentric loading it was found that the discs resistance to a change of angle was greatest in extension less in lateral flexion and least in forward flexion

Degenerated discs exhibited increased vertical deformation and less resistance to flexion. No horizontal instability was found in the material investigated.

In roentgenographic studies of vertebral motion in vivo increased horizontal displacement in disc degeneration was reported by Knutsson (1944), Gianturco (1944), Fletcher (1947) and Schalimtzek (1958).

Brown, Hansen and Yorra (1957) performed tension tests to failure in samples from the annulus fibrosus of two intervertebral discs. Considerable variation was found and tensile strength values of up to 0.12 Kp/mm² were reported. The most peripheral areas of the annulus anteriorly and posteriorly exhibited the highest strength values.

The strength of the vertebral body has been the subject of many investigations (Rauber 1876, Messerer 1880, Lange 1902, Göcke 1926, 1931, Bartelink 1957, Perey 1957, Decoulx and Rieunau 1958, Fie 1966, Weaver and Chalmers 1966).

In cubes of fresh bone from lumbar vertebrae tested parallel with the long *axis of the bone Rauber (1876) found an average compressive strength of* 0.81 Kp/mm². In whole vertebrae Messerer (1880) reported values between 0.22—0.78 Kp/mm². Lange (1902), who loaded specimens consisting of three vertebral bodies and intermediate discs and performed direct extensometer readings of deformation, reported strength values of 0.15—0.56 Kp/mm². In lumbar vertebrae tested in an Amsler machine Göcke (1926, 1931) found failures occurring at loads between 0.57—0.70 Kp/mm². The values reported by modern workers are in complete agreement with these previous investigations. In cubes obtained from the center of vertebral bodies Weaver and Chalmers (1966) found average values for failure in compression of 0.32 Kp/mm². They reported a decrease in strength and mineral content of the samples with increasing age.

In axial compression tests of vertebrae and discs failure occurs first at the end plate as pointed out by several authors (Perey 1957, Brown, Hansen and Yorra 1957, Decoulx and Rieunau 1958, Rolander 1966). Perey (1957) reported average values for the resistance of the end plate of 1.09 Kp/mm² or 600 Kp total load in the 20—30 years age group and 0.43 Kp/mm² or 260 Kp total load in the group over 60 years of age. These figures are in the same range as those found by other investigators. Rolander (1966) demonstrated that fracture of the end plate occurs at the load at which deformation curves for disc and vertebral body tend towards one another.

Theoretical calculations of the forces acting on the lumbar discs based on simple lever principles are in complete disagreement with the known physical properties of the individual spine components. For example, Bradford and Spurling (1945) calculated that a load of 1000 Kp would be excerted in the lumbar discs when lifting a 160 Kp weight from the floor in a position of forward bending.

Davis (1956, 1959), Bartelink (1957), Morris, Lucas and Bresler (1961), Eie and Wehn (1962) found by direct measurements that an increase in pressures occurs within the thorax and abdomen in the early stages of lifting. It is thought that this mechanism decreases the forces acting on the spine.

During moderate and heavy exercise the axial pressures acting on the lumbo-sacral spine were calculated to be within the range of 0.06 to 0.15 Kp/mm² (Eie 1966). The abdominal musculature was said to have a relieving effect and to represent approximately 40 per cent of the contraction force of the erector spinae.

EMG studies have shown that in the early stages of lifting, when the forces acting on the spine are presumably the highest, the activity of the erector spinae muscles is very low, while the abdominal muscles are very active (Floyd and Silver 1955, Bartelink 1957, Morris, Lucas and Bresler 1961). In full trunk flexion the erector spinae muscles are completely relaxed (Floyd and Silver 1955, Carlsöö 1961). Davis, Troup and Burnard (1965) in chrono-cyclophotographic studies of spine motion demonstrated that there was little intrinsic movement of the lumbar spine during the early phase of lifting. Extension of the lumbar spine was delayed until the weight was raised for about a third of the distance, when the occurrence of maximal intervertebral compression forces was no longer likely.

Nachemson (1966) has performed intradiscal pressure measurements in living subjects. The approximate load acting on the third lumbar vertebra in a 70 kg individual in the sitting position was calculated to be 142 Kp. Standing the load was 99 Kp, supine under anaesthesia 20 Kp. The highest values occurred with the subject sitting, leaning forwards and lifting a weight and were in the range of 270 Kp. Tangential tensile stresses in the posterior annulus fibrosus were calculated and the highest value recorded in the forward tilting and weight bearing position was 0.73 Kp/mm².

General properties of collagen and ground substance

Collagen

The mechanical properties of connective tissues depend in large proportion upon collagen, their structural protein. The collagen molecule or tropocollagen can be represented as a rodlike cylinder 3000 Å long and about 14 Å in diameter. It consists of three left handed helical polypeptide chains wound around a common axis to form a right handed superhelix. The aminoacid composition is characterized by a content of 1/3 glycine and a large proline plus hydroxyproline content (of the order of 2,9) (Piez 1966). This last feature provides a

properties of some tis ues within a certain time after death Wertheim (1847) found no changes in stiffness and strength of tendon nerve and artery of one dog five days after death

Gratz (1931) reported that fascia lata behaved a "essentially alive" within 18 hours following removal from the body Rigby Hirai Spikes and Eyring (1959) stored tendons in saline solution at 2° to 3° C and found no changes in properties "for as long as 1 to 2 months" Ridge and Wright (1965) reported no changes in tensile characteristics of skin within 18 hours after death

Viidik Sandqvist and Magi (1965) concluded from a study on rabbit knee ligament that no consistent changes in tensile characteristics were evident up to 96 hours following death The animals were stored intact at 18° to 20° C until shortly before tests and the experiments were performed in air

Contradictory statements have been advanced for ligaments Katzenstein and Fecher (1924) found increased stiffness and higher elasticity in ligaments 18 hours postmortem but admitted that the effect could be partly due to dehydration Annovazzi (1928) found the same effects in dog ligaments 10 hours after death and Smith (1951) claimed the same changes occurred within one hour but reported no figures

Preservation methods

Preservation in formalin has been reported to alter the mechanical characteristics of soft tissues (Stucke 1950 Elden 1964 a Viidik and Lewin 1966) and bone (Carothers Smith and Calabrisi 1949 Calabrisi and Smith 1951 McElhaney Fogle Byars and Weaver 1964 Evans 1964 Sedlin 1965 Sedlin and Hirsch 1966) The effect is the result of an increase in collagen cross linking induced by formaldehyde

Deep freezing has been said not to alter mechanical characteristics of tendons (Rigby Hirai Spikes and Eyring 1959 Van Brocklin and Ellis 1965) bone (Frankel 1960 Sedlin 1965 Sedlin and Hirsch 1966) skin (Ridge and Wright 1965) and intervertebral disc segments (Bartelink 1957 Hardy Lissner Webster and Gurdjian 1958 Nachemson 1960) Rabbit ligaments however exhibited significant differences in failure energy and dip incidence of the curves following deep freezing (Viidik and Lewin 1966)

The formation of ice from water is the most important physical change occurring when tissues are carried to low temperatures The freezing injury has both a mechanical and a chemical background (Meryman 1960) The first one is related to the size of the ice crystal a factor depending on the rate at which freezing proceeded and the temperature reached The chemical injury is produced as the growing ice crystals remove water from the tissues leaving behind an increased concentration of solutes the length of freezing state is of

importance in this connection In general temperatures of torage mu t be quite low at any rate below –39° C which is con idered to be the limit for super cooling

Air drying

Loss of ti sue water by air drying is well known to affect mechanical properties of biological material Wertheim (1847) howed that dehydration increa ed the stiffness and trength in ten ion of tendon mu cles arteries and nerves The load elongation curves approached a traight line E entially similar effects were shown later by Katzen tein and Fecher (1924) and Annovazzi (1928) in ligaments and by Stucke (1950) and Rollhäuser (1950 b) in tendons

The effect is al o present in bones Wertheim (1847) showed that elongation was more proportional to load in dry bone ti ue Rauber (1876) reported increased ela ticity in bending of femoral samples and increa ed breaking strength in femoral and humeral samples after drying

Evans and Lebow (1951) Dempster and Liddicoat (1952) Smith and Walmley (1959) Evans (1964) Sedlin (1965) and Sedlin and Hir ch (1966) found increa e in elasticity modules and strength of cortical bone after drying

Immersion in aqueous solutions

When in contact with aqueous olutions collagenous ti sues swell (Schade 1913 Kaye and Lloyd 1924 Lloyd Marriott and Pleass 1932, Kuntzel and Prakke 1933 Gu tavsson 1956)

In solutions free from salts welling is minimal at neutral pH and hows a well defined maximum in acid olutions and a poorly defined maximum in alkaline solutions Both maxima are repressible in the presence of salts (Lloyd Marriott and Pleass 1932) The nature of this process i complex O motic swelling occurs in solutions of acids and bases and is associated with the ionic protein groups Lyotropic swelling predominates in neutral solutions and is due to interactions of ions and molecules with the nonionic bonds of the protein (Gustavsson 1956)

The magnitude of swelling in a tissue is al o related to its degree of organization and the amount of internal tabilization of its proteins (*Kaye and Lloyd* 1924 Gustavsson 1956) The i olated fiber bundle of ox hide takes up more water than the whole hide A gelatin gel with the ame protein content as goat kin exhibits much greater swelling

The ground substance protein polysaccharides exhibit important interactions with water (Fessler 1957 Ogston 1966 Laurent 1966) and their amount and characteri tics are expected to affect the equilibrium swelling volume of connective tissues (Milch 1965)

The process is also age dependent in tendon swelling at neutral pH has been shown to decrease with age (Rollhäuser 1950 a Elden 1964 b)

Swelling of intervertebral disc samples in 0 9 per cent NaCl solution was shown by Göcke (1932) who also studied the swelling process in acid alkaline and salt solutions and showed decrease of water uptake with age Swelling in NaCl solution or water was illustrated by Naylor and Smare (1953), Bush Horton Smare and Naylor (1956) Hendry (1958) The annulus fibrosus exhibited less water affinity than the nucleus pulposus (Naylor and Smare 1953 Hendry 1958)

The process of swelling has been shown to alter the mechanical properties of certain collagenous structures Viidik and Lewin (1966) showed changes in tensile strength characteristics of rabbit knee ligaments after swelling in saline solution The load elongation and energy at failure were larger after four hours in saline solution than in control samples

Göcke (1932) showed increased deformation and reduced recovery in compression in intervertebral discs after swelling for 24 hours in 0 9 per cent NaCl solution However fluid was reported to improve recovery after compression tests in intervertebral discs by Ingelmark and Ekholm (1952) who perfused their samples with horse serum and Virgin (1951) who immersed the specimens in Ringer's solution

Tensile properties of collagenous tissues

Stress strain curves

Wertheim (1847) was the first modern scientist to investigate the tensile properties of body tissues In tests of human tendon muscle nerve and arteries he studied the characteristics of the load elongation diagrams Elongations were not proportional to load the hyperbole type of curves were convex to the load axis An equation was fitted to the curves with the form $Y^2 = ax^2 + bx$ and coefficients of elasticity derived from it Wertheim also illustrated the effects of air drying and postmortem changes

All successive investigations have shown the same general characteristics of the load elongation diagrams with an initial toe of varying magnitude followed in some cases by a straight line before plastic flow occurs

Different interpretations have been advanced to explain the shape of the load elongation diagram In tendon Reuterwall (1921) and Rigby Hirai Spikes and Eyring (1959) related it to the stretching of the wave pattern seen with polarized light

In arteries it is thought to be due to the distribution of collagen and elastin

in the arterial wall Krafka (1939) determined elastic moduli of aorta ligamentum nuchae smooth muscle from human intestine and tendon and concluded that the collagen fibers were responsible for the straight line character of the upper half of the curve Reuterwall (1921) Burton (1954) attributed the initial part of the curve to the elastin component and the final slope to the collagen fibers of the arterial wall A more complex relation including smooth muscle has been presented by Apter (1964) and Apter Rabinowitz and Cummings (1966)

Dick (1951) also concluded from studies on skin that the elastic fibers were responsible for the initial resistance to elongation Kenedi Gibson and Daly (1965) related the appearance of the stress strain diagram to a progressive orientation of the collagen fibers in the tissue They interpreted their stress strain curves in power law form a method used for collagen fibers by Morgan (1960) and discussed earlier by Scott Blair (1944)

Ridge and Wright (1965) who also performed tension studies in human skin found that the initial part of their curves could be fitted to a mathematical function that described the straightening and orientation of the fibrous material The second stage of extension was interpreted in power law form and characterized the stretching of orientated collagen

General rheological properties

It is now generally accepted that the mechanical properties of collagenous tissues are complex and that important viscous and perhaps plastic effects are present (Harkness 1966)

Roy (1880) in tensile studies on arterial strips defined an elastic and a viscous component and illustrated time dependent effects The presence of residual deformation after loading in cartilage and its time dependance was reported by Cocke in 1928 and by Hirsch in 1944

Gratz (1931) illustrated in fascia lata a sigmoid curve hysteresis loop behavior and residual deformation after loading The same characteristics were shown by Stucke (1950) in tendons

Smith (1954) in rabbit ligaments found elasticity to submaximal loads of short duration A viscous body type of response was found with the same loads during a longer period

Rigby Hirai Spikes and Eyring (1959) showed that in tendons mechanical behavior was reproducible as long as strain did not exceed 4 per cent values otherwise the tendons became progressively easier to extend and values up to 35 per cent could be reached With repeat tension cycles (Rigby 1964) rat tendons became increasingly stiffer and exhibited less hysteresis and slight

increase in length. Complete recovery of mechanical properties of the samples occurred after a ten minute period of rest between extensions.

In repeat stress relaxation tests in rabbit ligaments Vudik (1966) showed the phenomena to be larger on the first test, no changes occurred in subsequent tests independently of the resting period between them. In joints stress relaxation was illustrated by Johns and Wright (1961), in skin by Ridge and Wright (1965), in bone by Smith and Walmsley (1959) and by Sedlin (1965).

McElhaney (1965) and Sedlin (1965) described time dependent effects in the deformation properties of bone and showed that deformation was a function of the rate at which it was induced.

The complex rheological properties of tissues including time dependent and plastic effects have been expressed in mechanical model form in recent years. Appropriate combinations of three basic elements, elastic, viscous and plastic, in series or parallel, with linear or exponential characteristics can be used to define the rheological properties of most materials (Reiner 1958). It is difficult however, to ascribe specific anatomical elements to the constants of such models (Sedlin 1965).

Effect of fiber orientation

The geometrical disposition of the collagen fibrils is of primary importance in determining the mechanical properties of connective tissues. In tendons where the bundles of fibers lie in close relation with each other and parallel to the long axis of the structure, extensibility is low and tensile strength high (Elliott 1965). In skin, where a loose three dimensional network with a less evident symmetry is present, extensibility is of high magnitude and tensile strength lower than in tendon (Harkness 1961).

Evidence shows that collagenous structures are anisotropic; their response to stress varies in the different axis, a property related to the orientation of the fibrillar structures.

In compact bone according to Gebhardt (1905) and Weidenreich (1923) the collagen fibers are organized in lamellae alternating in a circumferential or longitudinal direction, arranged around the longitudinal axis of the Haversian system. Rauber (1876) showed differences in bending properties between longitudinal and transverse sections of cortical bone. Maj and Toajari (1937) found that bending strength was largest in the longitudinal axis of the bone and concluded that this characteristic mechanical anisotropy was the result of the arrangement and number of the collagen fibers. Dempster and Liddicoat (1952) found that the compressive strength of cortical bone was largest along the longitudinal axis while no differences were found between the radial and

tangential directions Hir ch and Da Silva (1967) illustrated the close relation between mall changes in fiber direction and trength of cortical bone

Gratz (1931) tated that fascia lata is resistant to tress in the longitudinal direction of the fibers while strength is low in the transver e direction

Harkness Harkness and McDonald (1957) pointed to the importance of the arrangement of the fibrous connective tis ue fibers in determining mechanical properties of the arterial wall Collagen fiber in the media of blood ve el may be organized in two ets of helices one right handed and one left handed arranged in alternating layers a pattern seen in mo t cylindrical organs (Harkness 1961)

Wolinsky and Glagov (1964) tudied the tructure of the arterial wall of rabbits at different di tending pres ures A progressive orientation of the fibrillar components was evident with increa ing pres ure from a random di tribution in the relaxed tate to a tight helical configuration of mall pitch at pres ures values close to the mean arterial pressure Di tinct differences in ten ile pro perties of specimens cut in the longitudinal or transverse axis of arteries has been reported by Roy (1880) Reuterwall (1921) Wilens (1937) Hiertonn and Jordan (1956) and Milch (1965)

Skin has directional effects in its tensile trength (Mendoza and Milch 1965) Tensile strength in rat skin is largest parallel to the wrinkle lines (Berard Wood ward Herrmann and Pula ki 1964) Human skin is more extensible across Langer s line than parallel to them (Ridge and Wright 1965) Abdominal skin shows more elongation at low loads in the longitudinal than in the circumferential direction of the body (Kenedi Gib on and Daly 1965) The ela tic properties of leather vary with the principal direction of the weave in the skin (Gu tavsson 1956) Studies of stretched kin in vitro howed that with increa ing extension increasing orientation of the collagen fibers in the line of force was evident until all fibers were parallel to the direction of the load (Gibson Kenedi and Craik 1965) It was concluded that variations in the collagen and ela tic fiber networks probably determine the variations due to age location and direction rather than the characteri tics of the collagen material it elf

Aging effects

Wertheim (1847) found that the coefficient of elasticity of bones tendons and nerves increased while the cohesion of the tis ues decreased with advancing age

Katzenstein and Fecher (1921) in human knee joint ligaments concluded that elastic behavior was most efficient in the 20 to 40 years old group Above and below this age exten ibility and residual deformation were larger Annovazzi (1928) found that ligaments from young rabbits were ea ier to deform and exhibited less elasticity than those from adult animal

Rollhäuser (1950 a) reported tensile strength values of 3 to 1.5 Kp/mm² in newborn tendon against 9 Kp/mm² in adult tissue. With age elongation was larger in the young group.

Curtis (1963) reported that old tendons have a higher elastic modulus than young ones using low rate of training. No differences were found at rapid straining rates (Elden 1964 a). In later report (Elden 1966) the changes in stress-strain behavior were found to be related to growth but not to senescence.

Rigby (1961) found similarities between the effect of repeat cycling of tendons and the aging effect in mechanical properties, X-ray diffraction pattern and shrinkage temperature. The tendon became stiffer, the residual deformation smaller, a more oriented pattern was evident with X-ray diffraction and the shrinkage temperature was higher.

Dick (1951) reported deformation of large magnitude in skin from old subjects and related this to changes in the elastic fiber network. Elden (1965 b) found no differences in stress-strain behavior of aging rat dermis. The transverse to longitudinal strain ratio was found to be age dependent and rise rapidly in old skin (Kenedi, Gibson and Daly 1965). Changes in tissue constants with age were reported by Ridge and Wright (1965). The normal tensile strength of Wistar rats was found to increase with age (Mendoza and Milch 1965).

Little or no differences were found as a function of age either in the deformation or recovery of adult articular cartilage in indentation elastometric studies (Sokoloff 1966). In fibrillated cartilage significant differences in elastic and recovery responses were earlier reported by Hirsch (1944).

Loss of extensibility with age well in advance of macro or microscopic changes in the structure of the arterial wall was shown by Roy in 1880. Essentially the same increasing stiffness has later been shown by many investigators (Wilens 1937, Krafka 1940 and others). Yater and Birkeland (1929—30) indicated in addition an increase in aortic extensibility up to the age of 27 years.

Material

This study was based on human lumbar spines obtained at routine postmortem examinations. A total number of 68 lumbar spines and 592 testing samples were investigated.

Sampling was limited to cases where the autopsy procedure was performed within 48 hours following death. The specimens were obtained as indicated by the experiments to be performed; no specific sampling system was used. The spine segments included from the twelfth thoracic to the first sacral vertebrae so that six intervertebral discs were obtained in every case. When possible all levels were used but occasionally discs had to be discarded because of damage at the autopsy procedure or extreme degeneration.

The study group is described in table number I. It includes spines from both sexes and different age groups. The experiments in which the different spines were used are listed in table II.

TABLE I *The study group*

Subject number	Autopsy number	Age (years)	Sex	Time in hospital (days)	Death to testing	Cause of death
1	I 1296	5	F	1	1 day	Bronchopneumonia
2	I 954	14	M	12	2 days	Head injury
3	I 1222	17	M	23	1 day	Cardiac failure
4	II 185	18	F	1	1 day	Malignant lymphogranuloma
5	I 976	19	M	16	1 day	Chronic glomerulonephritis
6	I 29	20	M	1	1 day	Circulatory failure
7	I 601	20	F	3	2 days	Cerebral contusion
8	V 10	21	M	—	2 days	Multiple trauma
9	I 428	22	M	113	2 days	Cardiac failure pulmonary hypertension
10	V 547	23	M	—	1 day	Multiple trauma
11	I 891	25	M	1	1 day	Uremia
12	I 1152	25	M	1	2 days	Electrocution
13	I 984	26	M	1	1 day	Poisoning
14	I 781	31	M	1	1 day	Respiratory failure
15	I 1395	32	F	60	10 hours	Uremia carcinoma cervix uteri
16	I 485	33	M	7	2 days	Rupture aneurysm internal carotid artery
17	II 86	34	M	46	1 day	Carcinoma testicle
18	I 1014	35	M	1	1 day	Subdural hemorrhage
19	I 962	35	M	63	1 day	Cerebral tumor
20	I 986	36	M	6	1 day	Pulmonary edema

Evaluation of the material

The spines were radiographically examined for signs of intervertebral disc degeneration (Knutsson 1944). Attention was paid to narrowing of the disc, presence of osteophyte and subchondral bone changes and accordingly the discs were classified as normal, moderately or severely degenerated.

All specimens were examined macroscopically and the degree of degeneration assessed in agreement with accepted standards (Lindblom 1944, Friberg and Hirsch 1950, Lindblom 1951, Virgin 1951, Hirsch and Schajowicz 1952, Ingelmark and Ekholm 1952, Naylor and Smare 1953). (Figs. 1, 2, 3 and 4.)

Grade 1. Normal discs. Annulus free from ruptures and shiny white, shiny white gelatinous nucleus.

Grade 2. The appearance is normal but the nucleus exhibits a more fibrous structure. A clear boundary is present between annulus and nucleus.

Grade 3. Isolated fissures in the annulus. The nucleus is dry and occasionally discolored. The boundary between the nucleus and annulus is no longer distinct.

Grade 4. Severe changes. Ruptures and sequestrae in both annulus and nucleus. Marginal osteophytes often found.

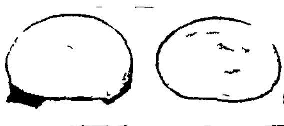


Figure 1. Macroscopic grade one

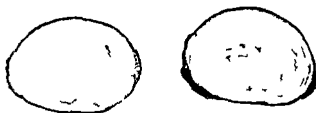


Figure 2. Macroscopic grade two

In agreement with earlier studies (Friberg and Hirsch 1950, Lindblom 1951) it was found that some discs with normal roentgenogram had undergone severe changes on macroscopic examination. Intervertebral discs with a macroscopic grading of 1 or 2 were used in the experiments dealing with the standardization



Figure 3 Macroscopic grade three



Figure 4 Macroscopic grade four

of method and with the evaluation of the general tensile characteristics of the tissue When studying the effects of age and degeneration discs from all ages and degeneration grades were included In these particular experiment the samples were examined histologically after the tensile tests were performed To evaluate the specimens the incidence and magnitude of several morphological changes were taken into account These alterations as described by Hirsch and Schajowicz (1952) were cavities filled with granular material cartilage metaplasia fissure presence of vascular or fibrous tissue An arbitrary grading system was used and accordingly the samples were divided in three groups 1) Normal or minimal degenerative changes 2) Moderate degeneration 3) Severe degeneration

Site of sampling

The general design of this investigation called for small specimens of uniform size and configuration Taking into account the morphology of the annulus fibrosus it was considered necessary to cut the samples parallel to the direction of its lamellae For these reasons the anatomical shape of the annulus limited the possibilities of sampling Anteriorly the annulus is thickest highest and least curved a feature that facilitated the preparation of specimen In most experiments the anterior annulus area was used as a sampling site and the samples were taken at a depth between 1 and 2 mm from the periphery A limited number of posterior annulus samples could be obtained and were used in the

evaluation of the tensile properties. The lateral segment of the annulus is markedly curved in lumbar discs, for this reason it was not possible to obtain satisfactory lateral specimens.

Methods

The specimens were prepared and tested within two hours of sampling to avoid the variables involved with the use of preservation methods. When not directly handled the spines were kept in closed polyethylene bags.

Environmental conditions

Sample preparation was done under controlled environmental conditions. The intention was to maintain a relative humidity of 100 per cent whenever the specimens were exposed to air. It had been previously determined that under these conditions loss of tissue water could be controlled. All the procedures were performed in a room with a total volume of 11 m^3 approximately, equipped with insulated double doors and special electrical outlets. The room temperature varied between 20 to 23° C. Humidity was produced with a commercial humidifier (Defensor 3001) with a vaporizing capacity of 4 liters of water per hour. Two standard hair type hygrometers (Inor) were used for control of relative humidity values. The humidifier was kept functioning constantly during the entire procedure and within 10 minutes the hygrometer readings showed 100 per cent relative humidity. A permanent foglike atmosphere and condensation everywhere in the room indicated almost constant saturation conditions.

Section of samples

After removing the longitudinal ligaments the intervertebral discs were dissected free and rectangular blocks were obtained from the anterior or posterior annulus. The blocks had 25 to 30 mm in length, the height of the disc in width and the thickness of the annulus. They were cut by sharp dissection following the contour of the inner part of the annulus. From these blocks it was intended to obtain sheets of constant thickness cut parallel to the fiber layers of the annulus. In the initial experiments these sheets were removed by sharp dissection using a Zeiss stereo microscope during the procedure. It was attempted to obtain a thickness of 1 mm but the dimensions of the samples were far from constant with this procedure.

In later experiments the specimens were cut with a Jung freezing microtome. This instrument is designed to cut very thin sections for histological

purposes. A calibration procedure was necessary to adapt it for the thick sections needed in this investigation. A dial displacement micrometer (Metron) measuring with an accuracy of ± 0.01 mm was used for this purpose. It was attached to the frame of the microtome and placed perpendicular to the table to measure its relative displacement. The feeding wheel of the microtome was then calibrated at 0.5 mm intervals and reference marks attached to it to provide reproducible section.

The blocks were flattened and frozen in the microtome table with a carbon dioxide snow stream. They were sectioned in sheets of 1.5 mm or 1 mm depending on the experiments to be performed.

A control was made to insure that sectioning was made parallel to the layers of the annulus later in the procedure when the final testing samples were ready. They were examined under a dissecting microscope and those not fulfilling this requirement were discarded.

Thickness measurements

In preliminary trials a micrometer eye piece was attached to a stereomicroscope and used as a measuring device. Although theoretically the accuracy of the system was within ± 0.01 mm with the magnification used, errors could be easily induced by slight changes in the position of the specimen or movements of the microscope.

A thickness gage was developed to permit contact measurements with a constant minimal force acting on the specimen distributed over a known surface area (fig 5). These requirements were essential as the material was not rigid and would creep under the influence of a load.

A dial displacement gage with an accuracy of ± 0.01 mm (Metron) was used as a measuring device. It was attached in a vertical position to a metal stand and kept balanced at a fixed distance from the measuring table by means of two thin flexible steel plates. This distance could be changed to allow measuring samples of different dimension. When not in use the system was kept unloaded with a spring device. A 2 mm thickness gage was used to zero the dial micrometer. The specimen was measured with a 1 mm thickness plate on top of it, the zero position represented in that way 1 mm thickness in the specimen. The combined weight of the plate and the force exerted by the micrometer represented a constant reproducible load of 0.13 p/mm² applied to the specimen during measurements. A small amount of creep was noticeable, seldom over 0.01 mm. The measurements obtained in this way represented the average thickness of the sheet.

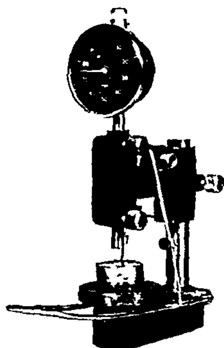


Figure 5 The contact thickness micrometer

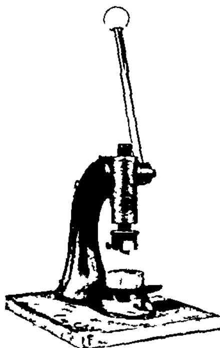


Figure 6 The modified press with a cutting die mounted

Stamping press

From the sheets final testing samples were made in a press and die assembly (fig 6) A punch press was modified to mount the cutting dies A round stamping table was manufactured of wood and covered with a layer of plexiglas first and soft plastic next to protect the sharp edges of the cutting devices The table could rotate around a central axis and a goniometer was incorporated in its base to allow die cutting of samples at varying angles Unless it is specifically stated all specimen were stamped along the long axis of the sheets



Figure 7 25×5 mm cutting die used in the early experiments



Figure 8 30×2 mm cutting die used for most experiments

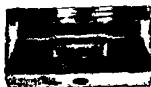


Figure 9 The cutting die with a reduced central section used in determinations of tensile strength

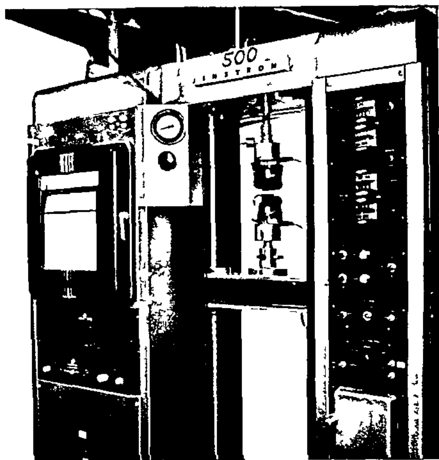


Figure 10 A detail of the Instron floor model tensile tester The recorder is at the left the control panel at the right The air compression clamps and jaws faces are mounted

Cutting dies and specimen size

The specimens were stamped with specially designed cutting dies These instruments were machined of steel subsequently hardened The cutting edges were sharpened at an angle of 15 degrees Three different dies were used A 25×5 mm die was arbitrarily chosen for the initial experiments related to the development of methods such as weight determinations during air exposure or swelling (fig 7)

For later experiments where tensile tests were performed two dies were designed The first one 30×2 mm in dimensions was used in the usual tensile tests (fig 8) The second one a die with a reduced central area of 10×2 mm and expanded end segments of 7 5×3 mm was employed for determinations of tensile strength (fig 9) When using the rectangular shaped die if one of the

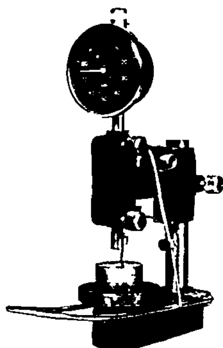


Figure 5 The contact thickne micrometer

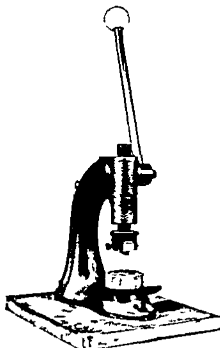


Figure 6 The modified press with a cutting die mounted

Stamping press

From the heet final testing sample were made in a pr and die a embly (fig 6) A punch pre was modified to mount the cutting dies A round tamping table wa manufactured of wood and covered with a layer of plexiglas fir t and soft pla tic next to protect the harp edges of the cutting devices The table could rotate around a central axis and a goniometer was incorporated in it base to allow die cutting of amples at varying angles Unless it is specifically tated all pecimens were tamped along the long axis of the heets



Figure 7 25×5 mm cutting die used in the early experiment

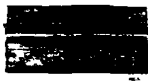


Figure 8 30×2 mm cutting die used for most experiment



Figure 9 The cutting die with a reduced central ec tion used in determinations of ten ile strength

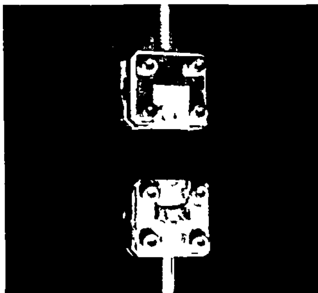


Figure 12 Detail of the alternate set of clamp

teristics allowing test under many different condition The force measuring system uses load cells with an accuracy of ± 1 1 per cent The cross head provide a constant rate of specimen deformation independent of the load with speeds varying from 0 02 cm min to 10 cm min Like the crosshead the chart of the recorder is driven synchronously over a wide range of speed The correspondence between the motions of the chart and cross head provides accurate record of sample extension The ratio of chart to cross head speed can be selected to give a large choice of extension magnifications

Clamps

The characteristics of the material are such that gliding during application of tension can represent a problem Special jaw faces were developed with matched blunt serration at 0 75 mm intervals and were fitted to the Instron air compression clamps With these clamps a constant known pressure can be maintained between the jaw The ideal pressure was found to be 1 5 kp cm² At this level no gliding occurred and in tensile strength experiments free space ruptures were obtained As these clamps are heavy and could not be adapted to the small capacity tension cell used when small load were required an alternate set of clamps was designed (fig 12) The jaws faces had the same 0 75 mm interval matching serrations and were tightened by means of four screws

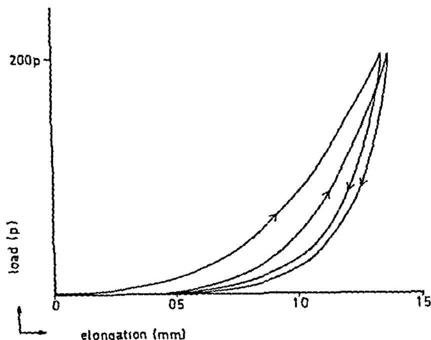


Figure 13 Load elongation diagram from a sample cycled twice to a load of 200 p

Methods of testing

All tests were performed in air in rooms where the temperature and relative humidity were controlled The room conditions in the experiments with the Instron floor model unit were 65 per cent relative humidity 21 degrees C temperature A relative humidity of 90 per cent and temperature 21 degrees C was employed when using the table model These conditions were accurate to ± 2 per cent The tests were accomplished within one minute of exposing the samples to air Humidity saturation conditions would have been desirable as discussed later However the testing machines belonged to and were located in other institutions where they were intensively used for other purposes a fact that made unpractical the development and installation of a suitable humidity chamber

Most tests were performed at a rate of deformation of 0 5 cm/min and a recorder paper speed of 50 cm/min providing a magnification factor of one hundred for readings of specimen elongation Due to the characteristics of the recorder this was the fastest rate of loading that allowed magnifications suitable to the size of the deformations occurring in the specimens

In most experiments the samples were cycled twice between zero and a given load (fig 13) In determinations of tensile strength the specimens were loaded to failure In stress relaxation experiments the distance between clamps was maintained constant after reaching a given value and the load was measured as a function of time

Parameters

The following parameters were evaluated from the load elongation diagrams 1) Elongation to a given load 2) Residual deformation 3) Energy dissipation The first two were read directly from the curves and expressed in mm Energy dissipation was determined by planimetry reading of the area under the loading and unloading curves Appropriate corrections for chart magnification and paper speed were made The energy values in p mm were normalized for specimen volume in mm^3 (p = pond) In the air drying and swelling experiments where the dimensions of the specimens changed after the original measurement and in the freezing tests where the samples were cut by hand the thickness of the specimens could not be determined with accuracy In these cases energy values were expressed in p mm

Elongation values provided information on the elastic stiffness of the material The residual deformation and energy dissipation reflected viscous damping effects

In the tensile strength experiments where the tests were carried to failure two parameters are reported ultimate strength in Kp/mm and elongation to failure in mm

Statistical methods

Standard statistical methods were used (Steel and Torrie 1960) Means and standard errors were employed as measures of central tendency and dispersion respectively Analysis of variance or Student s t test were applied to evaluate significance of differences between treatments When using analysis of variance Sheffe s contrasts method was applied to evaluate independent differences between means in multiple comparisons (Sheffe 1953) Product moment correlation was used in evaluation of relations between biochemical data and age

Linear regression analysis was employed to evaluate loss of weight as a function of time in samples exposed to air It was also applied in the study of relations between tensile properties and age

The 5 per cent level of probability was chosen as the criterion of statistical significance

Significance at the 5 per cent level is indicated by one asterisk* and at the 1 per cent level by three asterisks***

IV DISCUSSION OF THE METHODS AND RELATED EXPERIMENTS

In an investigation of this nature there are many factors that can influence the characteristics of the samples and modify their load deformation response. The methods finally adopted were based on a series of experimental procedures where these variables were evaluated. Consideration was given to the effect of postmortem changes, the environmental factors and the use of specific techniques for preparing or testing the samples. In evaluating postmortem and environmental influences the main subject discussed here is the water content of the tissue and the variations occurring due to these factors. In the study of specific techniques repetitive test and the use of a freezing microtome are considered.

Postmortem changes

The most evasive of the factors mentioned are of course the changes that occur after death. When using autopsy material there is a time lag between death and necropsy examination that escapes the control of the investigator. It appears however from a review of the experimental evidence available in relation to other tissues (Chapter II) that within a certain time following death at least three to four days, the tensile properties are not affected. In the publication where opposite conclusions were drawn, the effects of dehydration were possibly added or the experimental evidence was incomplete. The 48 hours postmortem sampling limit adopted in this investigation was empirically chosen based on the previous evidence.

In devising methods one of the main objectives was to maintain the water content of the samples at the same level as when removed from the body. It was of interest to know whether changes in the water content had occurred in the interval between death and sampling. This question was answered in the following experiment.

Variations in water content within 48 hours after death

For obvious reasons animals were used in this experiment. Two rabbits of similar age and weight were chosen. They were sacrificed with a heavy occipital blow and immediately after five intervertebral discs from each animal were chosen in a random fashion and removed. The incisions were closed and the animals stored at 4 degrees C for 48 hours. At the end of this period another group of ten discs was

sampled In a saturation humidity atmo phere the annulus fibro us was di ected from each di c The specimens were weighed in an analyti cal balance with an accuracy of ± 0 01 mg Subsequently the samples were vacuum dried at 2×10^{-3} mm Hg for 18 hours Weighing wa repeated and wet weight – dry weight differences calculated Water content was estimated as the ratio between this difference and the wet weight of the samples

$$\frac{\text{Wet weight} - \text{dry weight}}{\text{wet weight}}$$

Student s *t* test was u ed to evaluate the ignificance of differences i water content between the two group

Results The data is ummarized in table III

TABLE III *Water content of annulus fibrosus immediately after and 48 hrs following death*

Condition of ample	Wet dry weight / Wet weight	n
Fresh	0 ,3(+ 0 003	10
48 hours	0 "3, ± 0 011	10

t = 0 028 non ignificant

The differences between the two groups were not significant indicating tha the water content of annulus fibro us amples remained con tant for at lea t 4 hours following death

Environmental influences

When ti ues are removed from the body and are expo ed to a foreign environ ment their water content is the most labile factor to be influenced To avoid los of water in air the method adopted by many investigators is to immerse o expo e the amples to aqueous olutions in the e circumstances collagenou ti sues swell Evidence shows that tensile properties are significantly affecte in both ca es pointing to the necessity of a different method In the next erie of experiments the effects of environmental influences on annulus fibrosu samples was tudied and a solution to the problem was propo ed

Swelling of the annulus in different solutions

The following experiment was designed to study swelling characteristics of the annulus in four different media distilled water 0.9 per cent sodium chloride solution rheomacrodex (10 per cent dextran) and human plasma The last two solutions were chosen on the assumption that due to their osmotic pressure they would tend to minimize the amount of water uptake in the tissue

40 samples 20×5×1 mm in dimensions were obtained from the anterior annulus fibrosus of four different lumbar spines They were divided in a random fashion in 4 groups of ten samples each The samples were weighed fresh in an analytical balance to an accuracy of ± 0.01 mg They were subsequently placed in beakers containing the different solutions employed at room temperature They were removed at 5 min 30 min 1 hour 2 3 5 7 24 and 32 hours and weighed The surfaces were blotted for five seconds in filter paper prior to each weighing to remove excess surface liquid (Elden 1964 b) Swelling curves were obtained plotting weight vs accumulated time of swelling Original weights and fully swollen weights were used as variables in the statistical analysis

Results The samples exhibited considerable swelling in the four media investigated (fig 14) Water was accumulated at a rapid rate in the beginning until the process reached an equilibrium phase In distilled water the uptake was higher and equilibrium was reached in 2 hours In the other solutions equilibrium swelling was established within five hours and was of similar magnitude

The data is summarized in table IV

TABLE IV *Swelling of samples in different solutions*

Solution	Average original weight in gr	Average weight after swelling in gr	*n*	|t|
Distilled water	0.1066 ± 0.0054	0.2551 ± 0.0180	10	10.095 **
0.9 % NaCl	0.1017 ± 0.0020	0.1824 ± 0.0030	10	25.544***
Human plasma	0.0968 ± 0.0061	0.1702 ± 0.0090	10	8.528***
Rheomacrodex (10 % Dextran)	0.0920 ± 0.0020	0.1927 ± 0.0066	10	20.170***

The differences in weight before and after swelling were highly significant in all instances The shape and dimensions of the samples changed *making cross section measurement* inaccurate

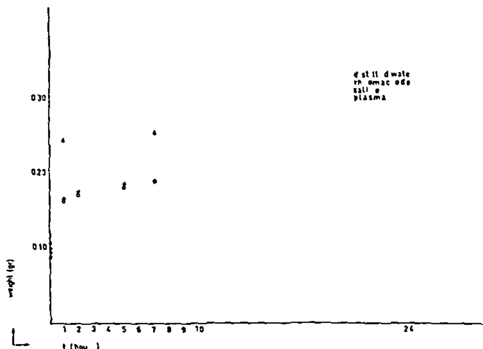


Figure 14 Swelling curves of anterior annulus fibrosus samples in different solutions

The effect of immersion in 0 9 per cent NaCl solution on tensile properties

Water uptake of considerable magnitude was induced by all the olution previou ly studied 0 9 per cent odium chloride was arbitrarily cho en to investigate the effects of swelling on tensile properties

Eleven anterior annulus samples 2×1 mm in cross ection were prepared They were te ted in tension and cycled twice to 200 p in air at 65 per cent relative humidity and 21 degrees C temperature They were then immersed in 0 9 per cent NaCl olution for five hours After swelling was completed they were retested as before Elongation to 200 p re idual deformation and energy dissipation were calculated from the curves The data for the first cycle is pre ented here Student s t test was used to evaluate the ignificance of differences before and after swelling

Results The evaluated data is summarized in table V

TABLE V *The effect of swelling in 0.9 per cent NaCl on tensile properties*

	Before swelling	After swelling in 0.9 % NaCl	n	|t|
Elongation mm	1.13±0.06	1.86±0.10	11	11.152***
Residual deformation mm	0.27±0.02	0.56±0.04	11	6.455***
Energy dissipation p mm	26.357±1.254	61.532±6.495	11	5.811***

Significant differences occurred in all the evaluated parameters. The samples became more extensible, the residual deformation and the energy dissipation were significantly larger (Fig. 15).

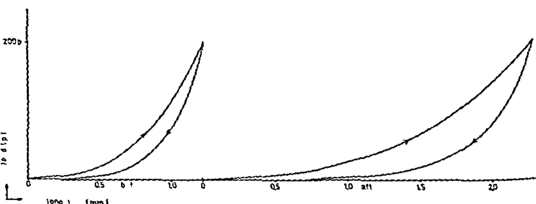


Figure 15 First tension cycle in one sample before and after swelling in 0.9 % sodium chloride solution

From these experiments it is concluded that immersion techniques are inadequate regardless of the solution used. To expose the samples to aqueous media without immersing them, for example wrap them in a compress soaked in 0.9 per cent sodium chloride solution, will bring about the same process of swelling although a steady state of equilibrium may not be reached.

Air exposure experiments

To study the process of water loss in air samples were exposed to atmospheres of controlled relative humidity and temperature The experimental conditions were produced in a specially designed box provided with automatic temperature and humidity control (Van der Valk 1965) The box was furnished with double walls made of plexiglas to provide dead space insulation and unobstructed view within the box and openings fitted with plastic gloves to allow work inside of the chamber without inducing humidity changes The dimensions of the box were 120×60×60 cm³ Humidity was produced by blowing air with a fan over a water container electrically heated to facilitate evaporation Drying was accomplished using a separate fan blowing over silica gel A psychrometer constructed with temperature sensitive diodes was used for automatic humidity control Changes in temperature were induced with an electric heater or a cooling coil which used circulating tap water Automatic temperature control was provided by means of a contact thermometer and a relay system A torsion balance weighing to an accuracy of ± 0 2 mg was placed inside the box (Figs 16 and 17)

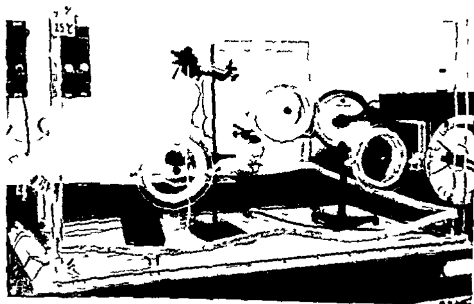


Figure 16 The plastic box used to expose samples to air with varying temperature and relative humidity

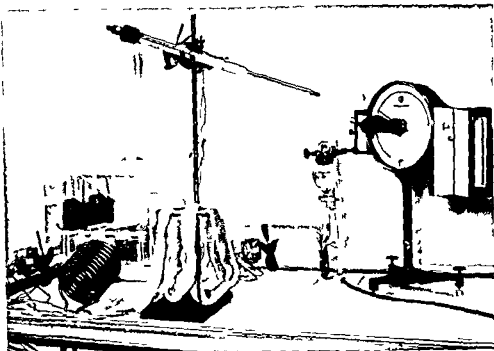


Figure 17 A detail of the contents of the box showing in the left posterior corner the humidifying — drying unit left anterior the water circulating cooling coil center anterior the electrical heater and mounted on the stand the contract thermometer center posterior the humidity control unit and to the right the torsion balance

45 samples 25×5×1 mm in dimension from the anterior annulus of four lumbar spine were divided at random in nine groups each to be expo ed to one of the following condition
Temperature 25 degrees C relative humidity 70 per cent 80 per cent and 90 per cent Temperature 30 degrees C relative humidity 70 per cent 80 per cent and 90 per cent Temperature 37 degrees C relative humidity 60 per cent 70 per cent and 80 per cent The capacity of the humidifying unit did not allow to obtain higher relative humidities than 80 per cent at 37 degrees C
Five samples were u ed for each setting of con tant humidity and temperature They were introduced in the chamber at one minute interval and weighed initially and every fifteen minutes for a minimum of two hours

Results Progressive lo s of weight occurred in all instances Plotting weight versus time in air a curvilinear relation is obtained but a straight line function can be a umed for the first 60 minutes interval (fig 18) A regression co efficient was calculated for each curve following the method of least squares and used a a variable in an analysis of variance for relative humidities at a given

temperature Independent compari ons between mean differences were made u ing Sheffe s contrasts method

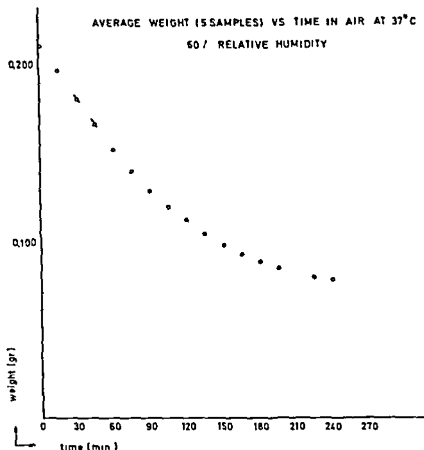


Figure 18 Loss of weight in air at 60 % relative humidity 37° C temperature illustrating a straight line relation during the first hour

The results are ummarized in Tables VI VII and VIII and the statistical analysis follows each table

TABLE VI *Loss of weight in air at 25 C temperature*

Relative humidity %	Pegression coeffici nt	n
70	0 415±0 017	5
80	0 303±0 004	5
90	0 133±0 006	5

ANOV for 25 C

V S	D.F	S S	M S	F
Between relative humidities	2	0 2009	0 1004	179.32***
Within groups	12	0 0068	0 0006	
Total	14	0 2077		

Average difference

Relative humidity %	80	90
70	0 111*	0 281*
80		0 170*

TABLE VII *Loss of weight in air at 30 C temperature*

Relative humidity %	*Regression coefficient*	*n*
70	0 412±0 013	5
80	0 300±0 002	5
90	0 131±0 006	5

ANOV for 30 C

V S	D.F	S S	M S	F
Between relative humidities	2	0.2001	0 1000	285 85***
Within group	12	0 0043	0 0004	
Total	14	0 2044		

Average differences

Relative humidity %	80	90
70	0 112	0 281*
80		0 169*

TABLE VIII *Loss of weight in air at 37° C temperature*

Relative humidity %	Regression coefficient	n
60	1.042±0.020	5
70	0.612±0.035	5
80	0.324±0.012	5

ANOVA for 37° C

V.S	D.F	S.S	M.S	F
Between relative humidities	2	1.2981	0.6491	218.54* *
Within groups	12	0.0357	0.0030	
Total	14	1.3338		

Average differences.

Relative humidity %	70	80
60	0.431*	0.716
70		0.285

The differences between regression coefficients of relative humidities at constant temperature were highly significant. If we plot these regression coefficients against relative humidity (fig. 19), it is evident that loss of tissue water is similar at 25 degrees C and at 30 degrees C. The water loss gradient is larger at 37 degrees C for comparable relative humidity values. All curves approach the zero value at a relative humidity of 100 per cent, indicating that at that point no loss of water would occur. Annulus fibrosus samples have a high content of loosely bound water. Water vapor diffuses to the specimen surface along a pressure gradient and the slope of the gradient determines the rate of transfer. When the gradient is eliminated (relative humidity 100 per cent) no loss of water occurs.

Following these conclusions the samples in the subsequent experiments of this investigation were prepared and handled in a room provided with a saturation relative humidity atmosphere. All the tensile tests performed in this study were of short duration: the samples were never exposed to air more than one minute. This implied minimal loss of water and consequently it was thought that humidity

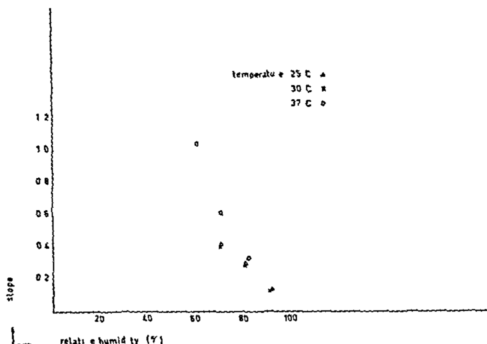


Figure 19 Average regression coefficients (slope) for curves of weight versus time during 60 minutes of air exposure plotted as a function of relative humidity

conditions lower than 100 per cent for such a short time should have negligible effects on tensile properties This assumption was confirmed in the following experiment

The effect of air exposure on tensile properties

This experiment was designed to answer the following questions 1) What is the effect of loss of water on tensile properties of annulus samples? 2) Do short periods of air exposure at 65 per cent relative humidity and 21 degrees C induce significant alterations in these same properties?

Sixteen samples 2×1 mm in cross section from the anterior annulus of two lumbar spines were prepared They were cycled twice to 200 p load at 65 per cent relative humidity and 21 degrees C temperature within one minute of being exposed to air The experiment was repeated after ten and sixty minutes of air exposure Elongation residual deformation and energy dissipation were calculated Data for the first cycle is presented here Analysis of variance and Sheffe's contrasts method were used to evaluate the differences between means

Results The data is summarized in table IX and illustrated in fig 20

TABLE IX *Effect of air exposure at 65 per cent RH and 21 C on tensile properties*

	Time of air exposure		
	1 minute	10 minutes	60 minute
Elongation mm	1.05 ± 0.04	1.01 ± 0.06	0.89 ± 0.11
Residual deformation mm	0.25 ± 0.03	0.29 ± 0.07	0.59 ± 0.11
Energy dissipation p mm	21.27 ± 1.80	25.86 ± 1.18	36.82 ± 3.03

The statistical analysis was as follows

ANOV elongation

V.S	DF	SS	M.S	F
Between times	2	0.1885	0.0942	7.39
Between samples	9	1.5077		
Within groups	18	0.2295	0.0127	
Total	29	1.9257		

ANOV Residual deformation

V S	DF	SS	MS	F
Between times	2	0.6691	0.3345	8.73
Between samples	9	0.4818		
Within group	18	0.6891	0.0382	
Total	29	1.8400		

ANOV Energy dissipation

V S	DF	SS	MS	F
Between times	2	939.759	469.880	16.94***
Between samples	9	743.397		
Within group	18	499.226	27.735	
Total	29	2182.312		

method the thickness of the samples was not very constant. Final dimensions were approximately 25×5×1 mm. The samples were tested in tension and cycled twice to 200 p at 65 per cent relative humidity and 21 degrees C temperature. They were then frozen under a carbon dioxide snow stream, allowed to thaw and tested again under the same conditions. Elongation, residual deformation and energy dissipation for the first curve are reported here.

Results. In table XI the data is summarized.

TABLE XI. *The effect of rapid freezing and thawing on tensile properties*

	Before freezing	After freezing	n	|t|
Elongation mm	1.30±0.07	1.29±0.10	16	0.019 non signif.
Residual deformation mm	0.40±0.05	0.45±0.04	16	1.320 non signif.
Energy dissipation p mm	30.16±2.69	30.85±2.80	16	0.295 non signif.

The differences before and after freezing were not significant. Rapid freezing to approximately −60 degrees C and immediate thawing did not alter the tensile properties of the samples.

This experiment justified the use of a freezing microtome. The conclusion on the effects of freezing are specifically not extended to other cases, such as the freezing method used commonly for preservation where the time element and temperature involved are of an entirely different magnitude (see chapter II).

V TENSILE PROPERTIES OF THE NORMAL ANNULUS FIBROSUS

Effect of fiber orientation

The geometrical arrangement of the collagen fibers is a major factor determining the tensile properties of collagenous structures. In most tissues it is possible to find a correlation between their response to stresses acting in the different axis and the spacial organization and orientation of the fibrillar structure (see chapter II). The fibers in the annulus fibrosus have two well defined axis of orientation. In the lumbar spine in each alternating lamellae the fibers run in a single direction opposite to the previous one and forming an angle with the horizontal axis of 30 degrees according to Rouviere (1921) or varying between 24 to 37 degrees according to Horton (1958).

In the following series of experiments the effects of fiber orientation on the tensile properties of the annulus fibrosus were investigated.

Tensile properties in different directions

A total of 114 specimens obtained from the annulus fibrosus of ten lumbar spines were used. As described previously blocks from the anterior annulus were dissected free. Sheets 1 mm in thickness were cut with a freezing microtome in the direction of the lamellae at 1 and 2 mm depth from the periphery of the blocks. From these sheets testing samples were die cut at the following angles: 0, 15, 30, 50, 70 and 90 degrees.

The samples were 2×1 mm in cross section, the length varied from 25 to 15 mm, the testing length was always 10 mm. The samples were cycled twice in tension to a 50 p load the first cycle and 100 p load on the second at 65 per cent relative humidity and 21 degrees C room temperature. Only values for 50 p loads are reported here as many specimens from the 70 and 90 degrees groups failed at the higher loads. Although 50 p represents a low stress level (0.025 Kp/mm²) it was necessarily used to compare samples with large differences in their physical properties.

Elongation, residual deformation and energy dissipation were measured from the curves and the difference between groups evaluated by analysis of variance and Sheffe's contrasts method.

Results The data is summarized in table XII and the statistical analysis follows

TABLE XII *The effect of angle of section*

Angle	Elongation mm	Residual deformation mm	Energy dissipation p mm/mm³	n
0	0 68±0 03	0 25±0 02	0 25±0 02	26
15	0 62±0 03	0 17±0 02	0 22±0 01	21
30	0 93±0 07*	0 29±0 06*	0 32±0 01*	19
50	2 37±0 02*	0 51±0 08*	0 68±0 10*	16
70	3 99±0 22*	1.33±0 18*	1 91±0 23*	13
90	5 03±0 17*	1 57±0 16*	2.35±0 18*	16 (a)

ANOVA Elongation

S V	D F	S S	M S	F
Between angle	5	312 993	62 599	254.35***
Within groups	103	26 580	0 246	
Total	113	339 574		

ANOVA Residual deformation

S V	D F	S S	M S	F
Between angles	5	32 021	6 404	48 44***
Within groups	109	14 278	0 132	
Total	113	46 299		

ANOVA Energy dissipation

S V	D F	S S	M S	F
Between angles	5	70 105	14 021	80 34***
Within group	106	18 498	0 175	
Total	111	88 602		

*) denotes significant differences from the value at 0 degree
(a) only 14 values in the energy dissipation group

ELONGATION IN MM FOR A 50 p LOAD
VS ANGLE OF SECTION

elongation (mm)	
5	
4	
3	
2	
1	

angle: 10 20 30 40 50 60 70 80 90

Figure 21

RESIDUAL DEFORMATION IN MM FOR A 50 p LOAD
VS. ANGLE OF SECTION

residual deformation (mm)	
2.0	
1.5	
1.0	
0.5	

angle: 10 20 30 40 50 60 70 80 90

Figure 22

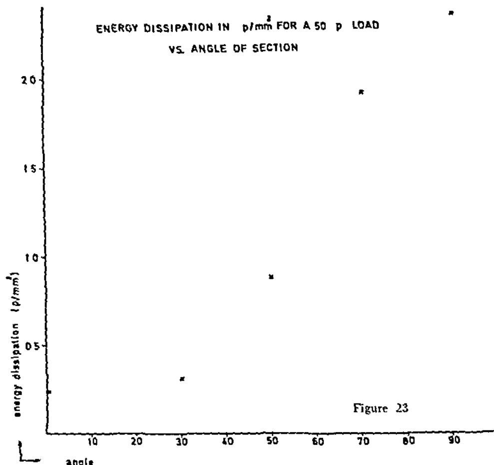


Figure 23

Small differences were present between the 0 and 15 degrees group The samples cut at 15 degrees tended to be stiffer and showed decreased elongation residual deformation and energy dissipation These differences were not significant From 30 degrees on the samples became progressively more extensible and exhibited increasing residual deformation and energy dissipation reaching the highest value for the three parameters along the vertical axis (fig 21, 22 and 23)

Tensile properties at the horizontal axis and along the fiber direction axis in 1 5 mm thick specimens

In 1 mm thick specimens small differences were present between horizontal samples and those cut close to one of the main fiber direction axis This was thought to be a function of the geometry of the tissue In a thin sample where

a limited number of layers is present overrepresentation of one fiber direction may occur. If the sample is cut along that axis it will be stiffer and exhibit better recovery properties. The opposite situation may also arise. In the following experiment the thickness was increased in order to augment the number of alternating sheets of fibers.

18 specimens 2×1.5 mm in cross section from 3 lumbar spines were prepared in 2 groups of 9 each, one in the horizontal axis and the other at one of the fiber directions respectively. They were cycled twice to 100 p at 65 per cent relative humidity and 21 degrees C temperature. A higher stress level was used in this experiment to avoid variations that might exist when using the low part of the load elongation curve.

Results. The results are reported in table XIII.

TABLE XIII. *Tensile properties in horizontal samples and fiber direction samples*

	Horizontal	Fiber direction	|t|
Elongation mm	1.11±0.01	1.15±0.04	0.68 non significant
Residual deformation mm	0.31±0.03	0.36±0.03	1.04 non significant
Energy dissipation p mm mm^3	2.19±0.06	2.21±0.12	0.38 non significant

The differences between the two groups were not significant. In 1.5 mm thick samples where there are more alternating sheets of fibers than in 1 mm thick samples no difference exists between the horizontal and the fiber direction axis at the levels of stress applied in these experiments.

Tensile properties in the two fiber direction axis

In the previous experiment the angles of section were taken at random in relation to the right or left axis of symmetry of the specimen. It was of interest to determine if the tensile properties follow a mirror distribution and both fiber direction axis have the same characteristics.

16 samples 1.5 mm thick were obtained from three lumbar spines. They were divided in two groups of eight samples and each group die cut in one of the fiber directions. They were cycled twice to a load of 400 p at 65 per cent relative humidity and 21 degrees C temperature.

TABLE XVI *The effect of location on tensile properties of posterior annulus samples*

Depth from periphery mm	Elongation mm	Residual deformation mm	Energy dissipation p mm/mm³	n
1	1 36±0 09	0 27±0 04	1 07±0 21	7
2	1 52±0 12	0.32±0 08	1 61±0 24	6
3	1 73±0 16	0 67±0 11	1 93±0 37	6
4	2 07±0.31	0 91±0 12	2 00±0 46	5

The statistical analysis was as follows

ANOV Elongation

V.S	D F	S S	M.S	F
Between 1—4	3	7 2509	2.417	3 73*
Between A—P within 1—4	4	12 9640	3.241	4 98***
Residual	32	20 7039	0 647	
Total	39	40 9189		

ANOV Residual deformation

V S	D F	S S	M.S	F
Between 1—4	3	1 2696	0 4232	17.34***
Between A—P within 1—4	4	1 5503	0 3876	15 83***
Residual	32	0 7807	0 0244	
Total	39	3 6007		

ANOV Energy dissipation

V S	D F	S S	M.S	F
Between 1—4	3	2 4516	0 8172	5 48***
Between A—P within 1—4	4	1 3656	0 3414	2.29*
Residual	32	4 7680	0 1490	
Total	39	8 5853		

In the anterior annulus the most peripheral layer or layer 0 (annulus lamellosus) was more extensible and exhibited higher residual deformation and energy dissipation than the immediately adjacent one (layer 1) From layer 2 towards the midline the samples became progressively more extensible and showed increased residual deformation and energy dissipation The differences between layers 1 and 2 were not significant A similar pattern was evident posteriorly The differences were significant in all layers Elongation residual deformation

ELONGATION VS DEPTH FROM PERIPHERY

Figure 24 Elongation to a load of 200 p of anterior and posterior annulus fibrosus samples removed at different depths from the periphery

RESIDUAL DEFORMATION VS DEPTH FROM PERIPHERY

Figure 25 Residual deformation of anterior and posterior annulus fibrosus samples from different depths

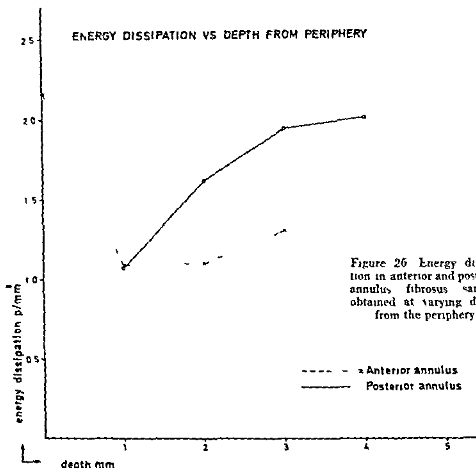


Figure 26 Energy dissipation in anterior and posterior annulus fibrosus samples obtained at varying depths from the periphery

and energy dissipation were significantly higher in the posterior than the anterior annulus

The average values for the angle between fibers was 52 ± 3 degrees in the anterior annulus and 59 ± 5 in the posterior annulus The differences were not significant ($t_{(30)} = 0.58$)

In summary samples from the anterior annulus were stiffer and had better recovery properties than posterior annulus samples Both anteriorly and posteriorly stiffness and recovery characteristics increased towards the periphery

Time dependent effects

The general characteristics of the tension cycles presented in this investigation showing hysteresis residual deformation and changes with succeeding cycles indicate a complex rheological behavior In biological materials elastic and viscous effects are well known to exist and plastic properties can be present

Combinations of these basic element have been u d to extr k \ model form Although no uch attempt is made here t e fol ov t c ment were performed to illu trate v cous characteri tic in th e u lu f

Behavior of samples under constant deformation

Ten samples 2×1 mm in cros ection from the anter c used The amples were loaded in ten ion at a rat of 0.5 cm/min at 90 per cent relative humidity and 21 C temperature The cro head of the testing machine were topp d a l of 200 p and deformation was kept con tant with the record r r in and regi tering load as a function of time durin a period of 60 cond

Results With con tant length a decrea e in tres occurred in all the amples The lope of the relaxation curve was calculated at its origin and again at 60 econd It was expre ed a $\tan \alpha = \frac{dP}{dt}$ where P i the load in pond and t the time in econd The averag initial lope wa $\tan \alpha_{t=0} = -31.85 \pm 1.26$ p ec The average lope after 60 econd wa $\tan \alpha_{t=60} = -0.34$ p/ ec

Tensile properties at different rates of deformation

7 anterior annulus samples 2×1 mm in cross ection were u ed The specimens were cycled twice in ten ion to 200 p at 0.5 cm min and a recorder peed of 50 cm/min They were allowed to recover for 10 minutes and retested to the am load at a rate of deformation of 5 cm/min and a recorder speed of 100 cm/min A higher rate of exten ion could not be used due to the peed of respon e of the recorder Tests were performed at 90 per cent relative humidity and 21° C temperature

Results Average values for the fir t cycle are summarized in table XVII

TABLE XVII *The effect of rate of deformation on tensile properties*

	Rate of elongation		n	|t|
	0.5 cm/min	5 cm/min		
Elongation mm	1.14±0.04	1.16±0.05	7	0.445 non significant
Re idual deformation mm	0.41±0.02	0.45±0.01	7	1.466 non significant
Energy di ipation p mm/mm³	1.30±0.06	0.98±0.11	7	3.315***

Elongation and residual deformation values showed no significant changes The energy dissipation during the cycle was lower at the faster rate of speed

The presence of stress relaxation and the fact that the response of the samples to stress was a function of the rate at which deformation was induced indicates that annulus fibrosus samples exhibit viscous damping effects

Tensile strength

Tensile strength is a fundamental rheological property of biological interest Its significance is enhanced when the range of stress to which a structure is subjected in vivo is known It appears in general that the safety factor of body tissues is relatively high (Harkness 1966)

Ruptures of the annulus fibrosus are a common finding in disc pathology Their relation to the etiology of disc herniation and the symptoms of low back pain has been discussed by Hirsch and Schajowicz (1952) As some of these ruptures for example the radiating type could be considered failures in tension data on tensile strength of the annulus fibrosus is of obvious interest

Determinations of tensile strength

The specimens in this experiment were divided in two groups The first one die cut in the direction of the fibers the second along the horizontal axis A special cutting die with a reduced central area was used Final sample dimensions were 10×2×1 mm in the central segment and 7 5×3×1 mm in the expanded end sections A total of 38 anterior annulus samples from six lumbar spines were tested Many samples had to be discarded prior to testing When using a parallel blade cutting die it was possible to discard just a part of the specimen if only one of the ends was not completely parallel to the direction of the sheets of the annulus With the reduced section die this was not feasible and provided a limit to the number of samples tested

The specimens were loaded in tension to failure at a rate of extension of 0 5 cm/min in air at 90 per cent relative humidity an 21° C temperature Values for ultimate strength in Kp/mm^2 and elongation to failure in mm are reported

Results Four samples showed failure at the clamp edges in the fiber direction group and two samples in the other They were excluded from the analysis

The average values for 18 samples cut along of the fiber direction axis were 0 90 ± 0 11 Kp/mm^2 for ultimate strength and 2 96 ± 0 16 mm of elongation

to failure The variation was rather large and was attributed to overrepresentation of a given fiber direction In four samples with low values this was evidently the case when examined under a dissecting microscope If they are eliminated the figures for tensile strength would be 1 07 ± 0 09 Kp mm² and elongation 3 15 ± 0 18 mm

15 samples cut along the horizontal axis showed average values for tensile strength 0.35 ± 0 03 Kp mm² and for elongation to failure 2.51 ± 0 17 mm The differences between the two groups are highly significant

Elongation and residual deformation values showed no significant changes. The energy dissipation during the cycle was lower at the faster rate of speed.

The presence of stress relaxation and the fact that the response of the samples to stress was a function of the rate at which deformation was induced indicates that annulus fibrosus samples exhibit viscous damping effects.

Tensile strength

Tensile strength is a fundamental rheological property of biological interest. Its significance is enhanced when the range of stress to which a structure is subjected in vivo is known. It appears in general that the safety factor of body tissues is relatively high (Harkness 1966).

Ruptures of the annulus fibrosus are a common finding in disc pathology. Their relation to the etiology of disc herniation and the symptoms of low back pain has been discussed by Hirsch and Schajowicz (1952). As some of these ruptures, for example the radiating type, could be considered failures in tension, data on tensile strength of the annulus fibrosus is of obvious interest.

Determinations of tensile strength

The specimens in this experiment were divided in two groups. The first one die-cut in the direction of the fibers, the second along the horizontal axis. A special cutting die with a reduced central area was used. Final sample dimensions were 10×2×1 mm in the central segment and 7.5×3×1 mm in the expanded end section. A total of 38 anterior annulus samples from six lumbar spines were tested. Many samples had to be discarded prior to testing. When using a parallel blade cutting die, it was possible to discard just a part of the specimen if only one of the ends was not completely parallel to the direction of the sheets of the annulus. With the reduced section die this was not feasible and provided a limit to the number of samples tested.

The specimens were loaded in tension to failure at a rate of extension of 0.5 cm/min in air at 90 per cent relative humidity an 21° C temperature. Values for ultimate strength in Kp/mm² and elongation to failure in mm are reported.

Results. Four samples showed failure at the clamp edges in the fiber direction group and two samples in the other. They were excluded from the analysis.

The average values for 18 samples cut along of the fiber direction axis were 0.90 ± 0.11 Kp/mm² for ultimate strength and 2.96 ± 0.16 mm of elongation

the histological characteristics of degeneration in the annulus fibrosus as described by Hirsch and Schajowicz (1952) cavities filled with granular material cartilage metaplasia fissures presence of vascular or fibrous tissue

The samples were divided on microscopical basis in three groups
1) Normal or minimal degeneration 2) Moderate degeneration 3) Severe degeneration

Results

Effects of age Only samples with a microscopic grade 1 were considered Elongation residual deformation and energy dissipation decreased progressively until age 26 after which they remained practically constant (fig 27 and 28)

Regression lines were calculated according to the method of least squares for the average values of subjects between 5 and 26 years In the group of samples above this age a regression analysis showed no significant age effects

The results are summarized in table XVIII and XIX

TABLE XVIII *Average values in samples below age 26*

Elongation mm	Residual deformation mm	Energy dissipation p mm/mm³	n
1.32±0 03	0 48±0 01	1.31±0 07	27

The regression lines were as follows Elongation 1 657–0 021 X residual deformation 0 782–0 019 X energy dissipation 1 978–0 010 X

All regression coefficients were highly significant

TABLE XIX *Average values in normal samples above age 26*

Elongation mm	Residual deformation mm	Energy dissipation p mm/mm³	n
1 03±0 02	0 29±0 01	0 93±0 02	69

The regression coefficient for each parameter were as follows Elongation –0 0030 residual deformation –0 0028 energy dissipation 0 0025 All regression coefficients were not significant indicating that no age dependent effects were present on the parameters evaluated

Effects of degeneration Samples above age 26 were evaluated as it was shown that in normal tissue no age dependent effects could be demonstrated above that point Degeneration grades 2 and 3 were pooled together and the differences

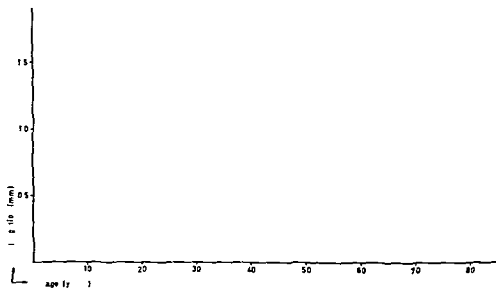


Figure 27

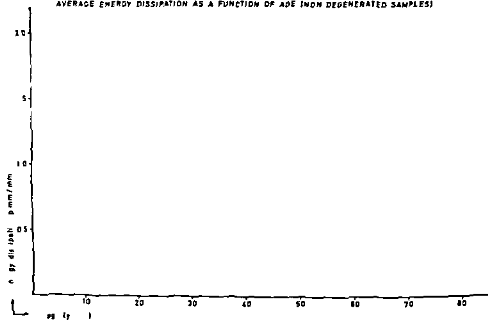


Figure 28

with samples graded as 1 were tested. Several samples failed before reaching 200 p and had to be discarded from the analysis. Histological examination showed a grade 3 degeneration in these samples.

Elongation and energy dissipation were significantly larger in the degenerated group of samples. No changes were observed in residual deformation (Table XX).

TABLE XX *Effect of microscopic degeneration on tensile properties*

	Condition of samples			
	Normal	Degenerated (Grades 2+3)	*n*	*t*
Elongation mm	1.03±0.02	1.31±0.03	97	10 **
Residual deformation mm	0.29±0.01	0.30±0.03	97	0.[illegible]
Energy dissipation p mm/mm³	0.93±0.0[illegible]	1.61±0.03	97	6.8

The effect of age and degeneration on some biochemical characteristics

In 10 cases a specimen immediately adjacent to the sample used for tensile tests was removed and processed for analysis of glycosaminoglycans, total hexosamine and hydroxyproline.

The content of glycosaminoglycans was determined by fractional elution of cetylpyridinium (CP) complexes as described by Antonopoulos, Gardell, Szirmai and de Tyssonsk (1964) and by a combination of this procedure with a technique recently developed by Antonopoulos, Gardell and Heinegard (unpublished).

The specimens were freeze dried and weighed. They were then digested with papain with the digestion mixture described by Antonopoulos, Gardell, Szirmai and de Tyssonsk (1964). 3 ml of that mixture were used for each sample. Aliquots of 50 ul were added to CPC micro-columns; four columns were used for each specimen. They were eluted with the following sequence of solvents: 1 per cent CPC, 0.3 M NaCl and 0.6 M $MgCl_2$. The fractions from two of the columns were treated as described in the original procedure. The average results from the two determinations are reported here for each specimen. The CPC fractions from the two remaining columns were evaporated and the residue was dissolved in 0.25 ml of 2.5 M NaCl. This solution was extracted with 1 ml of isoamylalcohol. The tubes were centrifuged and

lalcohol was carefully removed by a capillary pipette An
n of isoamylalcohol was added and the procedure repeated
t extraction with isoamylalcohol the aqueous phase was
ml of distilled water and this solution was passed through
OLA cellulose column (3×10 mm) This column was
N HCl followed by 6 N HCl The 0 02 N HCl fraction
nile the 6 N HCl fraction was analyzed for its content
described by Antonopoulos Gardell Szirmai and
4)

n other experiments (Antonopoulo Gardell, Szirmai
964 Antonopoulos 1965), that the 0 3 M NaCl and
fraction from the CPC cellulose column represent
d chondroitin sulfate respectively The 1 per cent
keratosulfates and the glycoprotein splitproducts
6 N HCl fraction from the ECTEOLA column
ulfate

amount of hexosamine in the specimen was deter
mined a ... drolysis of 20 ul aliquots of the digested sample
... Elson ... rgan reaction as modified by Antonopoulos Gar
dell Szirr ... on k (1964)

Hydroxyproline ... determined on aliquots from the digested samples
using the ... n and Glick (1956) modification of the Neuman
and Logan ...

Results

Effects of age The total hexosamine content showed a positive age correlation increasing up to the fifth decade and remaining then at a stationary level (r = 0 129) The 1 per cent CPC fraction which includes kerato ulfate and glycoproteins paralleled the total hexosamine pattern but showed a decrease after the fifth decade A positive age correlation was also present here (r = 0 59) The same characteristics and a positive age correlation were shown by the 0 3 M NaCl eluted fraction containing hyaluronic acid (r = 0 518) The keratosulfate fraction 6 N HCl showed also the same appearance but the drop after the fifth decade was more pronounced and consequently the correlation coefficient with age became non significant (r = 0 250) The chondroitin sulfate fraction eluted with 0 6 M $MgCl_2$ remained largely stationary although tended to decrease with age The correlation coefficient with age was non significant (r = -0 070)

These observations are illustrated in figure 29

The hydroxyproline content did not show any significant age changes (r = 0 052)

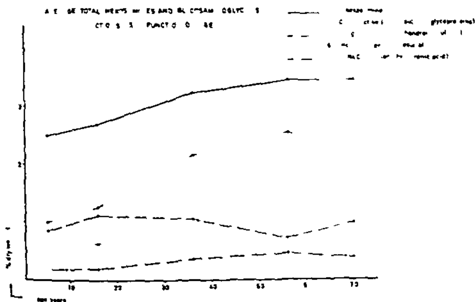


Figure 99 Average total hexosamines and glycosaminoglycans expressed in per cent dry weight as a function of age in non degenerated samples

The average hydroxyproline value for the whole group was 7 19 per cent dry weight or a collagen content of 55 12 per cent in dry weight Assuming a water content of 70 per cent we can derive 16 4 per cent of collagen in wet tissue

The results are summarized in table XXI

TABLE XXI *Average content in per cent dry weight of the various fractions in the different age groups*

Fractions per cent dry weight	Age in years				
	0—10	10—20	30—40	50—60	60—80
Hydroxyproline	8 00	8 13	7 77	6 00	7 60
Total hexosamines	2.50	2 68	3.23	3 44	3 43
1% CPC	1 00	1.26	2 15	2.54	2 17
0.3 M NaCl	0 19	0.20	0.36	0 46	[illegible]
0 6 M $MgCl_2$	0 85	1 12	1 05	0 72	0 99
6 N HCl	0 77	0 63	0 99	1 48	0 90

Effects of degeneration As in the evaluation of tensile tests the specimens were divided in two groups the first one including grade 1 samples and the second grade 2 and 3 specimens pooled together All samples showing degeneration were from subjects above 55 year They were compared with normal samples of

the same age group A t test was used to evaluate the differences between averages A significant decrease was observed in total hexosamine content 1 per cent CPC 0 3 M NaCl and 6 N HCl fractions No significant differences occurred in hydroxyproline and chondroitin sulfate (0 6 M $MgCl_2$ fraction) values (Table XXII)

TABLE XXII *Content of the different fractions in per cent dry weight in normal and degenerated samples*

Fractions per cent dry weight	Condition of samples		n	$\lvert t \rvert$
	Non degenerated	Degenerated		
Hydroxyproline	7 18±0 40	7 04±0 94	22	0 163
Total hexo amine	3 44±0 24	2 65±0 32	29	1 945*
1% CPC	2 27±0 13	1 52±0 19	29	3 243***
0.3 M NaCl	0 43±0 04	0 24±0 04	28	3 012***
0 6 M $MgCl_2$	0 88±0 11	0 81±0 10	29	0 429
6 N HCl	1 05±0 10	0 56±0 08	29	3 203***

In summary Between 5 and 26 years of age the samples exhibited in tensile tests progressively increasing stiffness improving recovery properties and decreasing internal damping effect After the middle of the third decade no significant changes in tensile properties were present as a function of aging

The biochemical parameters evaluated did not parallel the mechanical behavior of the samples in relation to aging A progressive increase in total hexosamines keratosulfate and hyaluronic acid was noticed up to the sixth decade followed by a drop of the last two fractions afterwards Chondroitin sulfate and hydroxyproline did not show age dependent changes

As a result of degeneration the sample became more easily elongated and showed increased energy dissipation Total hexosamines and glycosaminoglycans with the exception of chondroitin sulfate were significantly decreased

VII DISCUSSIO`

Some implifications are u eful when di cu in tl n of forces in the intervertebral disc Nachem on (1960) who analyz re s u ed for that purpose the analogy of a thin walled cylinder ul j ct real pres ure Accordingly the pres ure of the nucleu is tran mitt d t ulu in form of circumferential ten ile stresses Longitudinal ten il s mall or do not exi t due to the axial compres ive forces acting on the The characte ri tic mechanical response of the annulus could be fitted i oncept as it will preferentially resi t ten il tresses acting close to or th horizontal axis

The analy is was based on equilibrium con ideration ing that the tresses are uniformly di tributed across the thickne of tl f l termine the di tribution in a thick walled cylinder to which the an re favorally compares the deformation properties of the wall mu t l (Timo henko 1955 56) The internal pres ure will t radial com tangential ten ile tre es in the cylinder The radial compres ive tre t in the inner part of the shell and decrease toward the periphery ution of tangential stresses depends on the properties of the material homo geneous linear ela tic the stres es will be highest in the inn ecrea e outward If the wall is pla tic the opposite di tribution o in an ela tic cylinder the yield tress of the inner region is exc e wall becomes partly pla tic the tangential stresses increa e towar iphery until the elastic region is reached and decrea e afterward T mental data indicates that the annulus is non homogeneous and ha a cor heolo gical behavior Its tiffness and recovery properties and con equ re tance to forces increa e towards the periphery This could be l a a mechani m by which the internal layers "yield and provide for uniform di tribution of forces across the wall avoiding tres concentra n the inner regions

The pine is con tantly ubjected to motions involving varying nt of rotation around its longitudinal axis As a result of torsional forces sl e will be et up on a horizontal cross ection of the annulus If we a um ircular hape these tresses will be highest in the periphery and decrea e tow rd the midline a pattern followed by the properties of the annular wall

The characteristics of the po terior annulus uggest that under normal con ditions it is subjected to tangential ten ile tresses of lower magnitude than the anterior annulus As no ignificant differences were found in the angle at which

fibers cross between the anterior and posterior annulus we assume that the pattern of response to forces in different direction is similar in both areas

To understand the response of the fiber arrangement of the annulus to forces acting on one plane a simple analogy can be made The construction can be compared to a truss where two extensible rods are attached to two rigid plates above and below (Fig 30) The following situations are of interest

a) Extension of the truss (Fig 31) If the distance between the plates is increased by Δ the corresponding elongation of the rods δ is obtained from a geometrical study If the deformation is small i e $\Delta << L$
The result is

$$\sin \alpha = \frac{\delta}{\Delta} \quad \Delta = \frac{\delta}{\sin \alpha}$$

From this formula it is apparent that the truss is very extensible if α is a small angle because a relatively small elongation Δ of the rod corresponds to a large extension δ of the truss On the other hand if the angle is larger $\alpha \rightarrow \frac{\pi}{2}$ the truss becomes stiffer since then $\frac{\Delta}{\delta} \rightarrow 1$ and the extension of the truss could not occur without considerable deformation of the rods

b) For rotational motion (Fig 32) the truss makes no resistance at all if the midpoints of the plates are free to move If on the other hand they are fixed the resistance is small for all values of α as long as the angular motion is small since then the end points of each rod move approximately vertically and the deformation of the truss results from a translation but not a deformation of the rods For large angular deformation with fixed midpoints the resistance increases gradually according to fig 33

c) For horizontal translation the resistance is always large as it results in almost direct elongation of the rod

In the annulus similar conditions are met due to the small value of the angle between fiber As a result the resistance against angular motion is mainly due

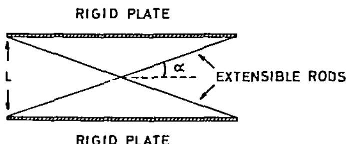
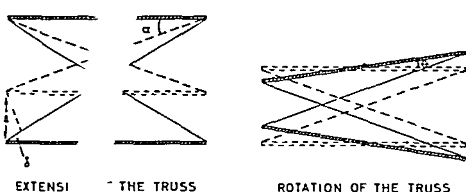


Figure 30



e 31

Figure 32

R SISTANCE TO ROTATION AS A FUNCTION OF ANGULAR DEFORMATION θ



Figure 33

o compre ion of the annulus in the concave side and to ligaments or mu cles n the convex ide as pointed by Rolander (1966) The resi tance to horizontal ran lation i large The annulu fibrosus provides minimal resi tance in tension o angular motions and maximal stability again t horizontal di placement

When testing samples in ten ion at low values of tre no differences were ound between horizontal samples and tho e cut along the direction of fibers However large differences were pre ent in tensile trength values between the wo groups Evidently a different mechani m of deformation is responsible for he behavior of samples at high level of stress It is generally accepted that in nost ti ues the first portion of the stre s train curves represents changes in rientation of the collagen fiber gliding along bundles or involves a ociated etworks such as elastin or mooth muscle Only at higher tress levels are the ollagen fibers directly subjected to ten ion effects In textiles similar model

concepts have been derived (Olofsson 1961) where straightening of the curved fibers in the fabric accounts for the initial elongation, while direct stretching of fibers only occurs in the high portion of the load elongation diagrams.

The ultimate strength of tissues is then a property that can be directly related to the collagen framework. For that reason values are often expressed in terms of collagen cross section area. Calculated in that manner the tensile strength of tendon would be 15 to 30 Kp/mm^2, of bone 50 Kp/mm^2, skin 10 Kp/mm^2, skeletal muscle 3 to 5 Kp/mm^2 (Harkness 1961). The differences are large and probably due to variations in orientation and linkages in the collagen network.

As pointed by Gustavson (1956) the mechanism of rupture in collagen fibers does not involve breaking of the main polypeptide chain (covalent bonds). A load of the order of 300 Kp would be required to rupture the weakest covalent linkage, the C—N bond of 14 Å length. It is possible that fiber bundles rupture by breaking the lateral cohesive forces between them so that fibrils glide over each other until failure occurs.

The values obtained in our experiments are actually not representative of the tensile strength of the fibers as theoretically only one half of these are running along the axis of the specimen. If this fact is taken into account the tensile strength of the annulus samples would be around 2 Kp/mm^2. If we think in terms of strength per unit collagen we can derive figures of 13 Kp/mm^2 assuming a collagen content of 16 per cent. These values are almost in a similar range as those calculated for cross sectional area of collagen in tendon and somewhat below than those found for isolated collagen fibers (Harkness 1961).

The tensile strength of the normal annulus is higher than the ultimate strength in compression of the endplates and vertebral body. This is in agreement with experimental and clinical observations indicating that trauma will produce fractures of the vertebrae but not disc herniations.

The same is not true in samples exhibiting morphological alterations. In that case significant differences with normal tissue were demonstrated in tensile behavior and in biochemical content. Degenerated samples showed a less efficient behavior in tension, they were easier to elongate and their recovery properties were decreased. Some samples actually failed at the loads used in the tests which represented approximately 30 per cent of the tensile strength of normal specimens. The safety factor of the degenerated disc is decreased and ruptures could occur as a result of stresses of not unusual magnitude. From a morphological viewpoint degeneration is seen first in the inner regions of the disc and progresses outwards. The same pattern is exhibited by the radiating ruptures affecting initially the deepest layers of the annulus and extending later to the more peripheral ones. This supports the concept that it is not the normal tissue that fails as a result of tangential or nearly horizontal stresses but that affected by degenerative processes.

In the vertical direction however tensile strength is low even in normal tissue and horizontal type of ruptures could occur due to relatively small vertical tensile forces.

The collagen content of the samples was not altered by degeneration processes. The changes in load deformation response must be related to other factors such as observed decrease in mucopolysaccharides, diminished cohesive forces between fibers and in later stages disruption of the normal framework. The protein polysaccharide compounds are considered to be of great importance in the determination of the mechanical properties of connective tissues (Schubert 1966). The observed decrease in polysaccharide fraction reflects an alteration in these protein complexes which evidently affect the behavior of the fiber construction.

As it has been pointed in relation to other connective tissues age affected tensile properties at a stage in life where changes can be related to maturation. From the third decade on the tensile characteristics remained unaltered and no correlations could be derived with the significant increase exhibited by some of the mucopolysaccharide fraction.

VIII SUMMARY

Low back pain has for long been interpreted as a symptom of intervertebral disc disease and has often been explained in mechanical terms For that reason the response of the disc to forces has been the subject of repeated investigations A correct interpretation of mechanical behavior requires knowledge about the load deformation characteristics of the individual components of the disc The annulus fibrosus is an integral part of it playing a most important role in its function and pathology An investigation of the tensile properties of the lumbar annulus fibrosus was therefore performed in postmortem specimens A total of 592 samples obtained from 68 lumbar spines were used

Before undertaking the study of tensile characteristics an investigation of the laboratory conditions and methods of preparation and testing was made and the following conclusions were derived

1) No changes in water content of samples from rabbit s annulus fibrosus could be demonstrated up to 18 hours following death

2) Immersion of samples prior or during testing in different solutions to avoid water loss was found to be an unsatisfactory procedure Swelling of considerable magnitude was induced in distilled water 0 9 per cent sodium chloride solution human plasma and 10 per cent dextran

The tensile properties of the specimens were significantly altered by water uptake as shown after swelling in 0 9 per cent sodium chloride solution The samples became more extensible residual deformation and energy dissipation were significantly larger

3) By exposing samples to air at different relative humidities and temperatures it was determined that loss of tissue water would not occur or be minimal at a relative humidity of 100 per cent Water loss was a function of the relative humidity in the air

A relative humidity of 100 per cent was used whenever the samples were exposed to air during preparation procedures

4) Loss of water by exposure for one hour to air at 65 per cent relative humidity and 21° C temperature induced significant changes in tensile properties The samples became stiffer but residual deformation and energy dissipation also increased With ten minutes of exposure to the same conditions no significant differences were obtained

Consequently environmental conditions of 65 per cent or 90 per cent relative humidity and 21° C temperature were used in tensile tests with a duration not exceeding one minute of air exposure

5) Ten minutes following a tensile test the samples recovered their properties justifying the performance of repetitive tests in the same specimen

6) Rapid freezing with a carbon dioxide snow stream and immediate thawing did not affect the tensile response of the samples enabling the use of a freezing microtome for sectioning purposes

Methods based on these experimental conclusions were used in an investigation of the tensile behavior of the lumbar annulus fibrosus

The response of the annulus to forces varied according to the direction in which the samples were cut The tissue was stiffest and exhibited lowest deformation and energy dissipation between the horizontal axis and an angle of 30° Samples cut at increasing angles were more extensible and had poor recovery properties showing a minimum along the vertical axis

The annulus is not a homogeneous structure in its response to stress Stiffness increased and recovery properties improved from the midline to the periphery across the thickness of the annulus in samples tested along the horizontal axis The most peripheral anterior layer showed poor recovery properties and was more extensible than the immediately subjacent tissue The anterior annulus was stiffer and had less residual deformation and smaller hysteresis cycles than the posterior annulus

The tensile strength of normal annulus tissue was investigated along the horizontal axis and along one of the fiber direction axis Average values of 0 35 Kp/mm² were obtained for horizontal samples and 0 90 Kp/mm² for specimen cut along the direction of the fiber With the assumption that only one half of the fibers were running along the long axis of the specimen values around 2 Kp/mm² were estimated The tensile strength for collagen cross section was 13 Kp/mm² assuming a collagen content of 16 per cent

Annulus fibrosus samples exhibited stress relaxation when elongated to a constant deformation The deformation was found to be a function of the rate of elongation energy dissipation significantly decreased when the samples were tested at a higher rate of deformation All the evaluated parameters elongation residual deformation and energy dissipation in samples cycled to a load of 200 p decreased with age from ages 5 to 26 After 26 years no significant differences were found between the different age Degenerated samples evaluated by histological examination exhibited significantly higher values for elongation and energy dissipation than specimens showing normal histological characteristics

Specimens taken from areas immediately adjacent to the tested samples were used for determinations of hydroxyproline total hexosamines and fractionation of glycoaminoglycans

No significant changes with age were found in hydroxyproline values The average content of hydroxyproline was 7 19 per cent dry weight of tissue

Collagen values of 16 4 per cent wet tissue were calculated from these figures assuming a water content of 70 per cent

Total hexosamines increased with age until the fifth decade and remained constant in normal samples With the fractionation procedures the same pattern (although with a decrease in values after the fifth decade) was exhibited by the 1 per cent CPC fraction which includes keratosulfates and glycoproteins the 0 3 M NaCl fraction composed of hyaluronic acid and the 6 N HCl fraction containing keratosulfate Chondroitin sulfate remained approximately constant

Total hexosamines and some of the glycosaminoglycans were significantly decreased in degenerated samples Degeneration did not affect chondroitin sulfate and hydroxyproline content per unit dry weight of tissue

These experimental results showed a well defined pattern of response in the annulus fibrosus to tensile forces in various areas and along different axis A simple analysis of the fiber construction confirmed the experimental conclusions The annulus extends with ease along the vertical axis and provides little resistance against angular motion elongation of the fibers is minimal in these circumstances On the other hand resistance against horizontal displacement is very large In this way the two basic properties of stability and motion are provided

The tissue exhibited considerable tensile strength almost in the range of tendons when the values were expressed in terms of collagen content After the third decade of life, the tensile properties of the samples were not influenced by age Degeneration however induced significant alterations in the load deformation response of the tissue decreasing its mechanical efficiency

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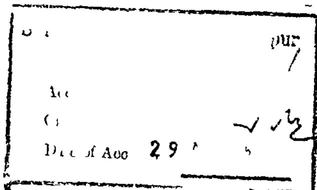
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ARS INGVAR HANSSON

AILY GROWTH IN LENGTH OF DIAPHYSIS EASURED BY OXYTETRACYCLINE IN RABBIT ORMALLY AND AFTER MEDULLARY PLUGGING



Acta Orthopaedica Scandinavica
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From the Department of Histology and the Department of Orthopaedics
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BY

LARS INGVAR HANSSON

MUNKSGAARD
Copenhagen 1967

Translator L J Brown
Statistical adviser K Svensson

LUND 1967
CARL BLOMS BOKTRYCKERI A B

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INTRODUCTION

Numerous clinical and experimental investigations have been published on the effect of so called growth stimulating operations on the growth in length of shaft bones (for surveys see Goff 1960 Tullard and Morscher 1965) but only few have included simultaneous examination of the morphology of the growth zones This was mainly because no methods were available for measuring the growth in length in various growth zones during a single day and at the same time allowing examination of the morphology of the growth zones

The aim of the first part of the present investigation was to ascertain whether it is possible to measure the daily growth in length from various growth zones with simultaneous morphological examination of the zones The purpose of this was to find out whether intravital marking of the endochondral growth process of the diaphysis can be used to determine the growth in length from the growth plate of the diaphysis which is mainly responsible for the growth in length of the shaft bones

In the second part a so called growth stimulating operation was studied for its effect on the growth in length of the diaphysis and the morphology of the relevant growth zones

CHAPTER I

THE LONG BONE AND ITS GROWTH IN LENGTH

A Introduction

Stephen Hales (1731, 1748) was the first to show that the long bones grow in length only at their extremities With an awl Hales bored two holes in the shaft of a bone of one of the limbs presumably a tarso metatarsal bone (Lacroix 1951) or tibia (Payton 1932 Bisgard and Bisgard 1935) in a chicken Two months later the chicken was killed and the distance between the two markings had not increased in the meantime On the other hand other parts of the bone had increased considerably in length especially the proximal part Hales therefore concluded that growth in length occurs in the cartilaginous areas at the extremities of bones and especially in the area with a cartilage plate between the head and the shaft of the bone Some years after this discovery by Hales John Belchier (1736 a and b) discovered that dentine and bony tissue in pigs and bony tissue in chickens fed madder root stained red Duhamel (1739 1742 1743 a b and c) studied bone growth with the aid of madder and found that only the bony tissue formed when the animal was fed madder turned red while that formed before and afterwards was of normal colour Using different methods Duhamel confirmed Hales finding that growth in length occurs at the extremities of the long bones but claimed that interstitial growth also occurs to a varying extent in diaphyses He was also able to show that transverse growth of the shaft occurs by appositional bone formation from the periosteum and not by interstitial growth in the bone tissue

John Hunter (1800 1835) repeated Hales and Duhamel's experiments and found that long bones grow only at their extremities He also found that appositional bone formation is accompanied by resorption of previously formed bony tissue According to Hunter this co occurrence of bone formation and resorption holds for longitudinal as well as for transverse growth of long bones

Flourens (1841, 1842, 1845, 1847, 1861) confirmed Hunter's conclusion by studying the longitudinal and transverse growth by means of subperiosteally implanted pins, rings, balls, plates of metal and partly by experiments with madder root. He also found that resorption of the bony tissue is not confined to the endosteal aspect of the diaphysis but occurs also in most parts of bony tissue, which also applies to appositional bone formation.

Ollier (1867) believed that the long bones grow only at their extremities but pointed out that in young animals slight interstitial growth can occur in the metaphysis.

The assumption that long bones grow in length only at their extremities has since often been confirmed by different methods, which have also shown that the growth occurs mainly within the growth plate of the diaphysis and that the rest is due to growth of the epiphysis (Humphry 1858, 1861, 1862; Wegner 1874; Dubreuil 1913 a, b and c; Digby 1916; Keith 1919, 1920; Muller 1924; Haas 1926; Harris 1926, 1931, 1933; Gatewood and Mullen 1927; Payton 1932, 1933, 1934; Bisgard 1933; Brash 1934; Silfverskiöld 1934; Bisgard and Bisgard 1935; Banks and Compere 1941; Boerema 1942). In contrast to Policard (1941), Lacroix (1951) found perichondral ossification to play no essential part in the growth in length of long bones.

According to Enlow (1963) the previously mentioned cartilage plate had been demonstrated several hundred years before its function had been realised. The first detailed description of its morphology was given by Muller (1858). The endochondral growth process has since been described more or less exhaustively by several workers in this field (Müller 1924; Weidenreich 1930; Harris 1933; Bloom and Bloom 1940; McLean and Bloom 1940; Lacroix 1951, 1961; Weinmann and Sicher 1955; Trueta and Morgan 1960; Sissons 1961; Gardner 1961; Leblond and Greulich 1961; McLean and Urist 1961; Bloom and Fawcett 1962; Hall 1965; Ham and Leeson 1965; Siffert 1966).

B. Long Bones and Growth in Length

1. VARIOUS REGIONS

Long bones, because of their mode of growth, belong to the group of bones known as cartilage bones. They increase in size by chondral growth including perichondral and endochondral growth (Keith 1948,

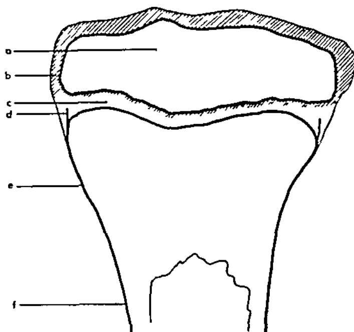


Fig 1 Proximal tibia of 30 day old rabbit

a bony epiphysis
b growth cartilage of epiphysis
c growth plate of diaphysis
d perichondral lamella
e metaphysis
f shaft proper

Gardner 1961 1963 Bloom and Fawcett 1962 Bargmann 1964 Bucher 1965 Ham and Leeson 1965)

Long bones are divided into different parts according to their development and growth But there appears to be no generally accepted nomenclature for this division which has caused considerable confusion It might therefore be convenient to define the names used for *different parts of long bones discussed in the present investigation*

The long bone is divided into a middle portion which is called the diaphysis or the shaft (Harris 1933 Leblond et al 1950 Lacroix 1951 Weinmann and Sicher 1955 Kopsch 1955 Bloom and Fawcett 1962 Copenhaver 1964 Ham and Leeson 1965 Hall 1965) and two end regions

The shaft proper (Fig 1) is the middle part of the diaphysis and is of practically uniform diameter (Lacroix 1951) The spongy part of the diaphysis is called the metaphysis (Fig 1) which as indicated by

Flourens (1841 1842 1845 1847 1861) confirmed Hunter s conclusion by studying the longitudinal and transverse growth by means of subperiosteally implanted pins rings balls plates of metal and partly by experiments with madder root He also found that resorption of the bony tissue is not confined to the endosteal aspect of the diaphysis but occurs also in most parts of bony tissue which also applies to appositional bone formation

Ollier (1867) believed that the long bones grow only at their extremities but pointed out that in young animals slight interstitial growth can occur in the metaphysis

The assumption that long bones grow in length only at their extremities has since often been confirmed by different methods which have also shown that the growth occurs mainly within the growth plate of the diaphysis and that the rest is due to growth of the epiphysis (Humphry 1858 1861 1862 Wegner 1874 Dubreuil 1913 a b and c Digby 1916 Keith 1919 1920 Müller 1924 Haas 1926 Harris 1926 1931 1933 Gatewood and Mullen 1927 Payton 1932 1933 1934 Bisgard 1933 Brash 1934 Silfverskiöld 1934 Bisgard and Bisgard 1935 Banks and Compere 1941 Boerema 1942) In contrast to Policard (1941) Lacroix (1951) found perichondral ossification to play no essential part in the growth in length of long bones

According to Enlow (1963) the previously mentioned cartilage plate had been demonstrated several hundred years before its function had been realised The first detailed description of its morphology was given by Müller (1858) The endochondral growth process has since been described more or less exhaustively by several workers in this field (Müller 1924 Weidenreich 1930 Harris 1933 Bloom and Bloom 1940 McLean and Bloom 1940 Lacroix 1951 1961 Weinmann and Sicher 1955 Trueta and Morgan 1960 Sissons 1961 Gardner 1961 Leblond and Greulich 1961 McLean and Urist 1961 Bloom and Fawcett 1962 Hall 1965 Ham and Leeson 1965 Siffert 1966)

B Long Bones and Growth in Length

1 VARIOUS REGIONS

Long bones because of their mode of growth belong to the group of bones known as cartilage bones They increase in size by chondral growth including perichondral and endochondral growth (Keith 1948

femur tibia and fibula (Salter and Harris 1963) epiphyseal ossification centres appear and thus cartilage plates in both the proximal and distal cartilaginous end regions In the other long bones of the limbs epiphyseal ossification centres and cartilage plates appear in only one of the two end regions In the phalangeal bones the first metacarpal and metatarsal bone the cartilage plate is situated in the proximal end of the bone in the other metacarpal and metatarsal bones in the distal end (Lacroix 1951 Kopsch 1955) In the opposite end region of the above mentioned bones no epiphyseal ossification centre or cartilage plate develops and the diaphyseal endochondral ossification process continues in the cartilaginous epiphysis (Lacroix 1951)

The metaphyseal part of the cartilage plate (Fig 1) does not belong to the epiphyseal region but forms a region between the epiphysis and diaphysis It is from this region that the diaphysis grows in length and is therefore called the growth plate of the diaphysis (Levene 1964 Johnson 1964) This growth plate develops much earlier during the growth period than other parts of the cartilage plate (Gardner 1961 1963) and can also occur in growth regions where no cartilage plate or bony epiphysis occurs (Siffert 1966)

The extremities of long bones have also been divided by other systems which for various reasons appear less suitable than those given above According to some authors (Harris 1933 Weinmann and Sicher 1955 Bloom and Fawcett 1962 Hall 1965) the epiphysis does not include any part of the cartilage plate, while others (Leblond et al 1950 Trueta and Morgan 1960 Salter and Harris 1963) claim that the epiphysis also comprises the entire cartilage plate The epiphysis has sometimes (Lacroix 1951 Ring 1955 Goff 1960 Bevelander 1961) been regarded as identical with the bony epiphysis In addition it may be added that the epiphyseal cartilage is a term used to designate both the cartilaginous epiphysis (Gardner 1961 Bevelander 1961) and the cartilage plate (Dodds 1932 Dodds and Cameron 1934 Lacroix 1951 Weinmann and Sicher 1955 Ring 1955 Brodin 1955 McLean and Urist 1961) The term epiphyseal cartilage is therefore unsuitable (Bergenfeldt 1933 Salter and Harris 1963 Hall 1965)

As mentioned the growth plate or disc has previously been used as a term for that part of the cartilage plate that is responsible for the growth of the diaphysis (Levene 1964 Johnson 1964) According to Siffert (1966) also the primary spongy bone of the metaphysis belongs to the growth plate of the diaphysis but this classification appears less

the name is situated close to the cartilaginous growth zone (Lacroix 1951 Ham and Leeson 1965 Hall 1965) This division of the diaphysis or the shaft appears more suitable than for example the cylinder and the funnel (Leblond et al 1950 Leblond and Greulich 1961 Enlow 1963 Hall 1965) which refer only to the cortical bony tissue In some investigations the shaft has been divided into diaphyseal and metaphyseal regions the former part then including only the middle portion of shaft (Bhaskar et al 1950 Brodin 1955 Leblond and Greulich 1961 Enlow 1963 Salter and Harris 1963) This division appears less suitable because the terms diaphysis and metaphysis describe areas relative to the growth zone

The extremity of a long bone (Fig 1) is divided into an epiphyseal area and a cartilaginous plate which is situated between the above mentioned diaphyseal and epiphyseal areas and is called the growth plate of the diaphysis since it is responsible for the growth in length of the diaphysis

There are different types of epiphyses namely pressure traction (Salter and Harris 1963) and atavistic epiphyses (Hall 1965) Pressure epiphyses are often also called articular epiphyses (Salter and Harris 1963) Unlike pressure epiphyses (Salter and Harris 1963 Hall 1965) traction and atavistic epiphyses are nonarticular and usually do not take part in the growth in length of long bones and are therefore irrelevant

During the first part of the growth period the entire epiphyseal area consists of a cartilaginous epiphysis During the latter part of the period one or more epiphyseal or secondary ossification centres appear in the cartilaginous epiphysis (Bloom and Fawcett 1962 Copenhaver 1964) which occurs at different times in different epiphyseal areas (Weinmann and Sicher 1955 Gardner 1961 1963) These epiphyses therefore consist of one or more central bony epiphyses and of surrounding remnants of the cartilaginous epiphysis (Fig 1) These remnants form the growth cartilage of the epiphysis and of the bony epiphysis The epiphyseal part of the cartilage plate is part of the above mentioned growth cartilage of the epiphysis The superficial rests of the cartilaginous epiphysis bordering the joint cavity are usually called the joint or articular cartilage while those parts covered by perichondrium are called the cartilage of the sides of the epiphysis (Lacroix 1951)

In the major long bones to which belong the humerus radius ulna

2 TOTAL GROWTH IN LENGTH

As mentioned previously the growth in length of long bones is due to growth of the cartilaginous tissue at their extremities In both extremities of major long bones and in one extremity of minor long bones the above mentioned growth in length occurs in the growth plate and in the growth cartilage of the epiphysis In the opposite ends of minor long bones growth in length occurs in the cartilaginous tissue covering the end of the bone Conversion of these cartilaginous areas to bony tissue does not increase the total length of the bone but results in a growth in length of the diaphysis and the bony epiphysis (Lutken 1947 Bhaskar et al 1950 Weinmann and Sicher 1955) During the first part of the growth period the growth in length of the cartilaginous area is almost identical with that of the diaphysis and bony epiphysis which means that the cartilaginous areas retain their thickness During the latter part of the growth period the thickness of the cartilage gradually decreases because the rate in growth in the cartilaginous area during this period is somewhat lower than that of the diaphysis and bony epiphysis (Weinmann and Sicher 1955 Morscher et al 1965)

a *The Growth Plate*

The metaphyseal part of the cartilage plate (Fig 2) is responsible for the major part of the growth in length of long bones This growth is *interstitial and occurs by division and hypertrophy of the cartilage* cells and production of intercellular substance The degenerative process like the intercellular calcification chondrolysis and the endochondral ossification in the metaphysis does not increase the length of the bone but contributes to growth in length of the diaphysis The intercellular calcification in the cartilage matrix results in an increase in the strength of the transition between cartilaginous tissue and metaphyseal bony tissue (McLean and Urist 1961 Bloom and Fawcett 1962)

This part of the cartilage plate also increases transversely by interstitial growth (Langenskiold 1947 Weinmann and Sicher 1955) and by appositional growth from the perichondrium (Weinmann and Sicher 1955 Solomon 1966) and possibly also from the ossification groove (Lacroix 1951 1961) which is a very cellular area in the adjacent part of the periosteum

b *The Growth Cartilage of the Epiphysis*

The epiphyseal part of the cartilage plate (Fig 2) is responsible for a minor part of the growth in length of the bone in the same way

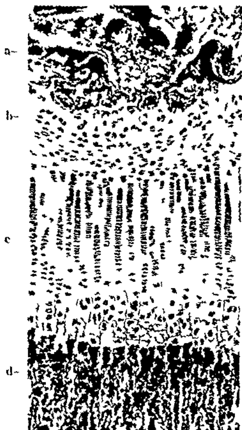


Fig. 2A. Distal radius of 20 day old rabbit (7×)

a bony epiphysis
b growth cartilage of epiphysis
c growth plate of diaphysis
d metaphysis

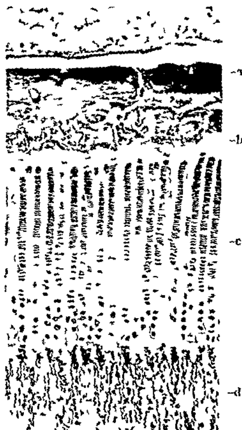


Fig. 2B. Distal radius of 40 day old rabbit (7×)

a bony epiphysis
b remnants of growth cartilage of epiphysis
c growth plate of diaphysis
d metaphysis

as the metaphyseal part. At the same time the bony epiphysis grows in diaphyseal direction from this cartilaginous area in the same way as the diaphysis grows from the metaphyseal part. Growth of the long bone and the bony epiphysis from this area occurs only during the earliest part of the growth period (Lacroix 1951, Ring 1955, Ham and Leeson 1965). Paxton (1933) and Guldhammer (1963) believe to have shown the occurrence of resorption of the bony epiphysis in this area during the latter part of the growth period which, however, could not be verified by even thorough investigations (Lacroix 1951, Trueta and Morgan 1960, Ham and Leeson 1965).

Those parts of the cartilaginous epiphysis which cover the peripheral part of the bony epiphysis (Fig. 1) are responsible for the rest of the growth in length of long bones. If the cartilaginous area borders the joint cavity and is called joint cartilage, growth occurs interstitially and if the hyaline cartilage is covered by perichondrium also appositionally (Weinmann and Sicher 1955). Growth of the bony epiphysis in peripheral longitudinal direction occurs in the same way as that previously described for the diaphysis (Muller 1924, Lacroix 1951, Weinmann and Sicher 1955, Ham and Leeson 1965, Hall 1965). The cartilaginous area alone is responsible for the growth in length at the extremities of the minor long bones which have no cartilage plate (Roche 1965).

C. Growth Apparatus of Diaphysis

This section is concerned with the growth plate and the adjacent zone of endochondral ossification in the metaphysis (Fig. 3) which together form the growth apparatus of the diaphysis (McLean and Urist 1961, Siffert 1966).

1. MORPHOLOGY

a. *The Growth Plate*

The above mentioned cartilaginous plate is conventionally divided into different zones according to the appearance and function of the cartilage cells. It has also been divided according to the intercellular calcification of the cartilage matrix which, however, is not limited to the growth plate but also occurs in the zone of endochondral ossification in the metaphysis (Gardner 1961, Bevelander 1961). Some authors have used a combination of various classification grounds. In the present investigation the growth plate is divided according to the function of the cartilage cells into the following zones: the zone of germinative cells, the zone of proliferative cells, the zone of hypertrophic cells and the zone of degenerative cells (Fig. 3) which is situated adjacent to the metaphysis. The above mentioned names indicate the function of the cartilage cells and appear to be preferable to a descriptive classification in this investigation.

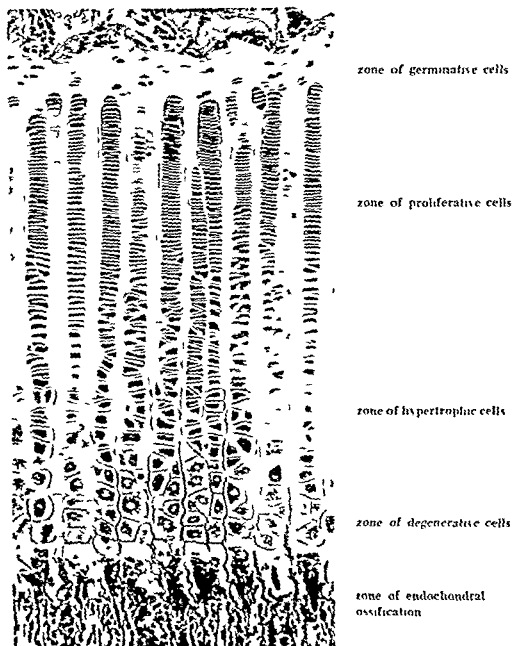


Fig. 3. Distal radius of 70 day old rabbit. Higher magnification of growth apparatus of diaphysis shown in Fig. 2B (400×).

THE ZONE OF GERMINATIVE CELLS

The zone of germinative cells (Fig. 3) comprises the most epiphyseal part of the growth plate

The cartilage cells are sometimes single and sometimes grouped (Trueta and Morgan 1960) and usually irregularly distributed (Hall 1965) in the zone The cell is as a rule elongated and ellipsoid with a small round dense and usually eccentric nucleus (Berthold 1954)

The zone is widest during the former part of the growth period With increasing age the zone decreases in height and is finally seen as a narrow zone (Dodds 1930 Dodds and Cameron 1934 Copenhaver 1964 Hall 1965)

In this part both matrix (Duthie and Barker 1955) and cartilage cells (Dodds 1930 Copenhaver 1964) are produced There are fairly numerous mitoses of which only a few can be seen in longitudinal sections of the bone while many can be observed in transverse sections (Lacroix 1951 Rigal 1962) According to Rigal (1962) the mitotic activity varies from species to species In rats mitoses are few while in rabbits they are numerous

There appears to be various synonyms for the zone of germinative cells *e g* the zone of reserve cells (Dodds and Cameron 1934 Lacroix 1951 Berthold 1954) the reserve zone (Ring 1955) the zone of reserve cartilage (Copenhaver 1964) the zone of resting cartilage cells (Trueta and Morgan 1960) the zone of resting cartilage (Ham and Leeson 1965) the zone of resting cells (Trueta and Little 1960) the zone of germinal cells (Trueta and Morgan 1960) the zone of undifferentiated cartilage cells (Trueta and Morgan 1960) and the basal zone (Lacroix 1951 1961)

THE ZONE OF PROLIFERATIVE CELLS

The zone of proliferative cells (Fig 3) is situated metaphyseally to the zone of germinative cells (Trueta and Morgan 1960) The former zone is as a rule wider than the latter (Hall 1965) and these two zones together form about half of the height of the growth plate (Trueta and Morgan 1960)

The cartilage cells in the zone of proliferative cells are as a rule arranged in columns of different length (Lacroix 1951 1961 Weinmann and Sicher 1955 Trueta and Morgan 1960 McLean and Urist 1961 Ham and Leeson 1965) or in groups of varying size (Dodds 1930 Dodds and Cameron 1934 Berthold 1954 Weinmann and Sicher 1955 McLean and Urist 1961 Salter and Harris 1963) The columns of cells extend in longitudinal direction of the bone (Weinmann and Sicher 1955 McLean and Urist 1961 Bevelander 1961 Ham and Leeson 1965) These columns usually start at the border of the zone of germinative

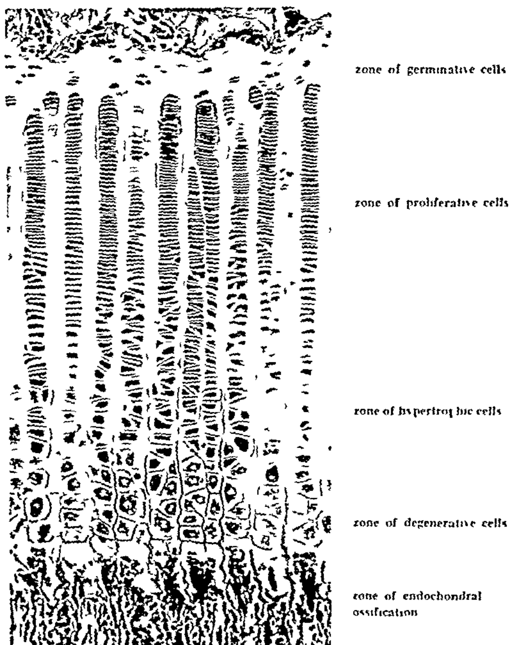


Fig. 3. Distal radius of [illegible]0 day old rabbit. Higher magnification of growth apparatus of diaphysis shown in Fig. 2B (190 ×)

THE ZONE OF GERMINATIVE CELLS

The zone of germinative cells (Fig. 3) comprises the most epiphyseal part of the growth plate.

(Dodds 1930 Trueta and Little 1960 Rigal 1962 Hall 1965) Rigal (1962) observed a relationship between mitosis in the column and in that cell in the zone of germinative cells which is situated closest to the epiphyseal part of the cellular column When this cell is undergoing division the cells in the column are in the resting phase Kember (1960) who used tritiated thymidine autoradiography in the rat found that the generation time of the most active cells situated in the middle part of the zone is between 1 and 3 days The generation time of the other proliferative cells increases in epiphyseal respectively metaphyseal direction which means that the activity is lowest near the borders of the zone The time for those that are nearest the epiphysis was up to 4 times as long as that for the most active cells This part of the column therefore represents a zone of reserve cells (Kember 1960) In addition as in many other tissues the frequency of mitosis show diurnal variation (Simmons 1962 Simmons and McLean 1962)

The appearance and development of the cellular columns have been the subject of various investigations The cells in a column are believed to derive from a single cell situated in the zone of germinative cells (Dodds 1930 Dodds and Cameron 1934 Weinmann and Sicher 1955 Lacroix 1961 McLean and Urist 1961) Later autoradiographic investigations suggest that a single mother cell gives rise to a large number of cells which continuously increase in number by repeated division in the zone of proliferative cells (Kember 1960 Messier and Leblond 1960 Rigal 1962) This means that only few mother cells are necessary

In this zone the cartilage cells produce large amounts of cartilaginous matrix which has been shown by autoradiography (Dziewiatkowski 1951 1952 Duthie and Barker 1955 Leblond and Greulich 1961)

The zone of proliferative cells has also been called the zone of palisade (Trueta and Morgan 1960) the zone of young proliferating cartilage (Ham and Leeson 1965) the zone of flattened cells and cell multiplication (Dodds and Cameron 1934) die Schicht der Knorpel saulen" (Tallard and Morscher 1965) the zone of cartilage cell columns (Morscher et al 1965) the zone of proliferation (Lacroix 1951 Trueta and Morgan 1960) the proliferating zone (Lacroix 1961 Hall 1965) and the proliferative zone (Trueta and Little 1960 Rigal 1962)

THE ZONE OF HYPERTROPHIC CELLS

This zone is on the metaphyseal side of the zone of proliferative cells (Fig 3) There is no distinct border between the proliferative and

the hypertrophic cells in a column because the maturation process is slow (Trueta and Little 1960) In addition proliferative cells in a column are sometimes intermingled with hypertrophic cells in adjacent columns presumably because the proliferative cells in one column divide at a different time than those in an adjacent column (Trueta and Little 1960 Rigal 1962)

In this zone in contrast to the previously mentioned zone the cartilage cells differ from one another in size The smallest cells are situated in the epiphyseal part of the zone the largest in the metaphyseal part (Dodds and Cameron 1934)

In the zone of hypertrophic cells the cartilage cells gradually mature during their passage through the zone towards the metaphysis (Kember 1960 Messier and Leblond 1960) At the same time the cartilage cells begin to increase in volume and loose their cuneiform appearance and become almost spherical or cubical This expansion of the cells occurs mainly in longitudinal direction of the column The transverse septa which formerly ran obliquely to the longitudinal axis of the column become more and more perpendicular In some cases the septum turns in the opposite direction with the result that it finally runs parallel to the column and the hypertrophic cells then lie adjacent one another Occasionally though rarely the cartilage cells retain their cuneiform appearance during maturation (Lacroix 1951 1961)

As a result of hypertrophy the cartilage cells expand in the longitudinal direction of the column to about 4 times their original length The cartilage cells also expand simultaneously transversely but not so markedly Since the longitudinal septa between the cellular columns also become narrower simultaneously the growth plate does not increase transversely The amount of intercellular substance is however not reduced but instead the longitudinal septa probably increase in length (Lacroix 1951 1961) Trueta and Morgan (1960) on the other hand believe that the intercellular substance is markedly reduced in association with hypertrophy of the cells and that the matrix becomes more compact than before and that the border between the intercellular substance and the cartilage cells becomes more distinct

During maturation of the cartilage cells larger and larger vacuoles appear in the cytoplasm because of the deposition of glycogen (Lacroix 1951 1961 Dixon and Perkins 1961 Ham and Leeson 1965) and fatty substances (Lacroix 1951 Bargmann 1964) During the hypertrophic stage the deposition is largest after which it abruptly decreases with the result that the most mature cartilage cells in the zone of hyper-

trophic cells have no glycogen deposits (Dixon and Perkins 1961 Lacroix 1961) During the latter part of the maturation process fluid accumulates inside the cells with the result that the cytoplasm and the nucleus have an oedematous appearance (Weinmann and Sicher 1955 Trueta and Morgan 1960)

The nucleus which in the zone of proliferative cells is situated peripherally in the cell migrates towards the centre during the hyper trophic process (Trueta and Morgan 1960 Tullard and Morscher 1965) At the same time it increases in volume and its structure becomes looser than before (McLean and Urist 1961)

In this zone the production of cartilage matrix is more intense than in previously mentioned parts of the growth zone This production is confined to that part of the zone of hypertrophic cells which is least mature and situated nearest the zone of proliferative cells In the meta physeal part of the zone there is probably no production of cartilage matrix (Duthie and Barker 1955 Leblond and Greulich 1961 Johnson 1964)

The zone of hypertrophic cells (Trueta and Morgan 1960 Trueta and Little 1960) has been known under various names such as the zone of cell growth (Dodds and Cameron 1934) the zone of maturing car tilage (Ham and Leeson 1965) the zone of maturation (Scott and Pease 1956) the hypertrophic zone (Lacroix 1951) the zone of progres sive hypertrophy (Lacroix 1961) the hypertrophying zone (Hall 1965) the giant cell zone (Trueta and Little 1960) and the zone of giant cells (Trueta and Morgan 1960)

THE ZONE OF DEGENERATIVE CELLS

Metaphyseally to the zone of hypertrophic cells is the zone of de generative cells (Trueta and Morgan 1960 Trueta and Little 1960 Park 1964) which reaches the metaphysis

This zone (Fig 3) includes the cartilage cells nearest the metaphysis in each column The border between the hypertrophic and the degene rative cells in a column is as a rule diffuse The cartilage cells reach maximum size in the zone of hypertrophic cells When these hyper trophic cells have reached the zone of degenerative cells vacuolisation of the cytoplasm continues simultaneously as the nuclei begin to de generate and to swell and loose large amounts of chromatin (McLean and Urist 1961) This degeneration process finally results in the death and desintegration of the cells (Trueta and Morgan 1960 Sissons 1961)

The lacuna which is situated close to the metaphysis is often called the clear cell because in many cases the lacuna appears to be empty (Irving 1964).

The number of cells in the zone of degenerative cells is small. According to Trueta and Morgan (1960) a column contains only one or occasionally two degenerative cartilage cells. However Dodds and Cameron (1934) like Lacroix (1951, 1961), Ham and Leeson (1965) and McLean and Urist (1961) reported that as many as four degenerative cartilage cells may be seen in the column.

Also this zone has been known under different names such as the zone of fully grown cells (Dodds and Cameron 1934) and the zone of cell death (Messier and Leblond 1960). Synonyms referring to the intercellular calcification are also often used such as the zone of calcification (Dodds and Cameron 1934, Lacroix 1951) and the zone of calcifying or calcified cartilage (Lacroix 1961, Ham and Leeson 1965) but these names are not synonymous with the zone of degenerative cells for they refer to the intercellular calcification process.

The hypertrophic and the degenerative cartilage cells are often referred to as belonging to a single zone known under different names such as the zone of edematous cells (Bhaskar et al. 1950), the zone of hypertrophic cells (Leblond et al. 1950) and the layer of hypertrophying or hypertrophied cells (Salter and Harris 1963).

b. *The Line of Erosion and the Metaphysis*

THE LINE OF EROSION

The border between the zone of degenerative cells and the metaphysis (Fig. 3) is well defined (Lacroix 1951). Chondrolysis of the degenerative zone occurs along this border. This process involves particularly the transverse septa and then the cellular lacunae are opened but smaller parts of the longitudinal septa are also destroyed. Chondrolysis occurs by cellular activity. These chondrolytic cells are believed to be either uninuclear mesenchymal cells such as capillary endothelial cells and connective tissue cells (Dodds 1932, Weinmann and Sicher 1955, Sissons 1961, Irving 1964) or multinuclear cells such as osteoclasts (Dodds 1932). According to Trueta and Morgan (1960) chondrolysis occurs in association with a sort of microhaemorrhage from blood capillaries along the line of erosion.

This line or narrow zone has also been known under such names as the erosion line (Cameron 1961), the zone of cartilage removal (Dodds

and Cameron 1934 Gardner 1961 Copenhaver 1964) the base of cartilage plate (Kember 1960) the erosion zone (Morscher et al 1965) and "die Eroffnungszone" (Bargmann 1964)

THE METAPHYSIS

As mentioned the metaphysis (Fig 3) is the spongy part of the diaphysis bordering the growth plate Its upper border which corresponds to the erosion line is thus distinct but its lower one bordering the shaft proper is diffuse (Lacroix 1951)

The metaphysis is built up of spongy tissue which is composed of two components namely cartilaginous matrix and bony tissue In longitudinal sections of the bone the metaphysis appears to consist of trabeculae which as a rule run in the direction of the longitudinal axis of the bone The central part of the metaphyseal trabeculae consists of cartilaginous matrix which is covered on both sides by bony tissue with the exception of a narrow zone close to the growth plate (Robinson and Cameron 1956) The cartilaginous central part is directly connected with the longitudinal septa in the growth plate (Ham and Leeson 1965) Transverse sections through the metaphysis show no trabeculae but instead cartilaginous parts forming walls in longitudinal tunnels whose inner wall is lined by bony tissue The type of the new formed endochondral bony tissue varies during the growth period but is always sooner or later replaced by lamellar bone (Lacroix 1951 Weinmann and Sicher 1955 Pritchard 1961 Enlow 1963 Frost 1963 b)

The spongy tissue of the metaphysis is made up of primary and secondary spongiosa Primary spongiosa is situated nearest to the growth plate and comprises that part where osteogenesis is very active and resorption of the longitudinal trabeculae is insignificant The trabeculae are therefore delicate dense and run uninterrupted through this part In the secondary spongiosa osteogenesis is not so active and many trabeculae are completely or partly resorbed The trabeculae in the secondary spongiosa are therefore sparser shorter and thicker than in the primary spongiosa (Sissons 1953 1961)

The peripheral parts of the metaphysis have also undergone thorough reconstruction and its transverse diameter has been reduced and is the same as the other parts of the diaphysis *i e* the shaft proper (Harris 1933 Lacroix 1951 Weinmann and Sicher 1955 Leblond and Greulich 1961 Enlow 1963) This results in elongation of the shaft proper at the same rate as the increase in length of the diaphysis by growth from the growth plate (Leblond and Greulich 1961)

c. The Endochondral Calcification

As previously mentioned, the intercellular substance is produced in the zone of germinative cells, the zone of proliferative cells and the adjacent part of the zone of hypertrophic cells, and is most active in the last mentioned zones. These areas show no signs of calcification in the intercellular substance. Robinson and Cameron (1956) therefore call this part the zone of uncalcified cartilage matrix. In the metaphyseal part of the zone of hypertrophic cells as well as in the zone of degenerative cells, calcium salts are seen in the intercellular substance. Similar deposits are also seen in the cartilaginous parts of the trabeculae of the metaphysis.

The border between intercellular substance with and without calcium salts is said to be at the level of hypertrophic cartilage cells nearest the metaphysis (Durning 1958, Trueta and Morgan 1960, Trueta and Little 1960, Ham and Leeson 1965) or at the border between the hypertrophic and the degenerative cells (Dodds and Cameron 1934, Robinson and Cameron 1956, Takuma 1960).

As a rule, the calcified part of the growth plate includes 1—4 cells in each column of cartilage cells (Dodds and Cameron 1934, Bloom and Bloom 1940, McLean and Bloom 1940, Lacroix 1951, 1961, Robinson and Cameron 1956, Durning 1958, Ponlot 1959, Trueta and Morgan 1960, Trueta and Little 1960, McLean and Urist 1961, Ham and Leeson 1965). There is said to be a definite ratio between the above mentioned number of cells and growth activity (Harris 1933, McLean and Bloom 1940, Bloom and Bloom 1940).

Robinson and Cameron (1956) divide the area with calcium salts in the cartilage matrix in two parts, namely the zone of cartilage undergoing calcification and the zone of completely calcified cartilage matrix. The border between these two zones can coincide with the erosion line (Leblond et al. 1950, Robinson and Cameron 1956), pass somewhat epiphyseal to the line in the growth plate (Bloom and Bloom 1940, McLean and Bloom 1940, Trueta and Morgan 1960, Trueta and Little 1960) or metaphyseally to the erosion line in the metaphysis (Gardner 1961, Bevelander 1961). This variation can be explained by the varying growth activity in different growth plates (McLean and Bloom 1940, Bloom and Bloom 1940, Gardner 1961).

The first sign of calcification in the intercellular substance along the border between the zone of uncalcified cartilage matrix and the zone of cartilage undergoing calcification occurs in the form of granules

situated singly or in small groups. These granules are situated pericellularly in the longitudinal septa but are not contiguous with the cells (Robinson and Cameron 1956, Scott and Pease 1956, Takuma 1960, Lacroix 1951) and are numerous at the level where the longitudinal septa are crossed by the transverse septa (Trueta and Little 1960). Further metaphyseally the corresponding area in the longitudinal septa undergoes calcification but also the central part of the septa which however is as a rule incompletely calcified (Robinson and Cameron 1956). Trueta and Little (1960) like Durning (1958) believe that it is the central parts of the septa that undergo complete calcification while the peripheral parts are not calcified.

Calcium salts are deposited also in the transverse septa but not to the same extent as in the longitudinal septa (Bloom and Bloom 1940, McLean and Bloom 1940, Lacroix 1951, Weinmann and Sicher 1955, Scott and Pease 1956, Durning 1958, Ponlot 1959, Trueta and Little 1960, Ham and Leeson 1965). This opinion is not shared by Dodds (1930, 1932), Dodds and Cameron (1934) and Robinson and Cameron (1956) who found no signs of calcification in these septa.

The metaphyseal calcified part of the growth plate is known by different names, very often as the zone of calcification (Dodds and Cameron 1934, Bloom and Bloom 1940, McLean and Bloom 1940, Lacroix 1951, Weinmann and Sicher 1955, Trueta and Morgan 1960, Trueta and Little 1960, Copenhaver 1964, Morscher et al. 1965) or the zone of provisional or preparatory calcification (McLean and Bloom 1940, Cameron 1961, McLean and Urist 1961, Bloom and Fawcett 1962, Salter and Harris 1963). Other names have also been used such as the zone of calcifying cartilage (Ham and Leeson 1965, Hall 1965) and the zone of calcified cartilage (Leblond et al. 1950, Gardner 1961, Leblond and Greulich 1961, Lacroix 1961).

In the present investigation the following terms are used: the zone of uncalcified cartilage, the zone of cartilage undergoing calcification and the zone of completely calcified cartilage.

d. *The Epiphyseal Part of the Cartilage Plate*

Though the epiphyseal part of the cartilage plate (Fig. 2) does not belong to the growth apparatus of the diaphysis, it might not be out of place to dwell on this area because it is of significance in the nutrition of the growth plate.

The epiphyseal part of the cartilage plate develops, as mentioned

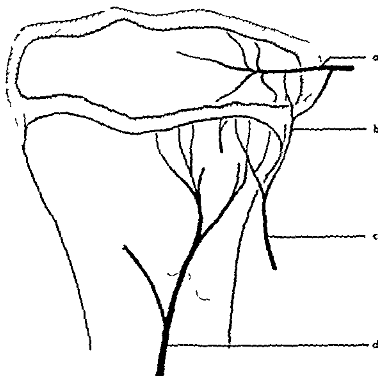


Fig. 4 Arteries in proximal tibia of 30 day old rabbit

a epiphyseal arteries
b perichondral arteries
c metaphyseal perforating arteries
d nutrient artery

During this period, by when the growth of the bony epiphysis from the epiphyseal part of the cartilage plate is complete, the epiphyseal vessels run first through the terminal plate of bone and then divide into short vessels which in turn divide into smaller ones that branch off perpendicularly and run parallel to the epiphyseal aspect of the cartilage plate. After a short distance each vessel divides into capillaries. This means that each artery that passes through the terminal plate of bone gives rise to about 24 terminal capillaries. No anastomoses are seen between these vessels when they have passed the terminal plate of bone, in contrast to the numerous anastomoses between vessels within the other parts of the bony epiphysis. The terminal capillaries extend through the calcified zone, where they form a flattened end region before they pass into the venous part which often but not always turns back through the same canal in the terminal plate of bone. The flattened part of the capillary covers an area comprising

four to twelve columns of cells whose epiphyseal ends usually converge towards the capillaries. The capillary endothelium often lies close to the tops of the columns of cells or adjacent to the germinative cartilage cells. The venous capillaries empty into venous vessels which after having passed the terminal plate of bone empty into the venous sinusoids in the bony epiphysis (Morgan 1959, Trueta and Morgan 1960, Irving 1964, Hall 1965). The sinusoids in the bony epiphysis empty via veins which leave the epiphysis in the same areas as those entered by the arteries (Nelson et al. 1960).

b. *The Metaphyseal Vessels*

The vessels that reach the metaphyseal border of the growth plate come from two different vascular systems (Fig. 4).

The vessels that reach the growth plate through the central part of the metaphysis are branches of the nutrient artery. The nutrient artery passes into the bone marrow cavity through a canal which often runs obliquely to the longitudinal axis of the bone. The vessel divides in the marrow cavity into an ascending and a descending branch (Morgan 1959, Brånemark 1959, Göthman 1961). As a rule there is only one nutrient artery, but in the femur there are often two (Trueta 1963). As to the tibia, after a short distance the ascending branch runs towards the proximal metaphyseal area of the diaphysis and divides usually into two to four branches. This arborisation occurs at a varying distance from the origin of the vessel (Göthman 1961). The branches run a straight course towards the metaphysis at the same time as they diverge. In the beginning they are situated in the posterior part of the bone marrow cavity but closer to the metaphysis one branch bends forwards while the others continue in the same direction. The main branch and the smaller branches give off small vessels to the cortex. The larger branches arborise richly in the area of transition between the shaft proper and metaphysis. The central branches of the vessels run along the longitudinal axis of the bone towards the growth plate, while the branches nearer the cortex usually follow this wall in the metaphysis and give off longitudinal branches to the growth plate. In the secondary spongiosa of the metaphysis the vessels branch richly. In this area fine arterioles develop which run in the primary spongiosa towards the growth plate. These vessels are straight and parallel and do not branch further but run as capillaries to the most metaphyseal degenerative cell in each column (Fig. 3), after which they turn and

run back to the bone marrow where they empty in the sinusoids As a rule one capillary reaches only a single cell column The capillary nearest the degenerative cell appears to be sinusoidally swollen and to consist only of a membrane and endothelial cells (Cameron 1961 Irving 1964) According to Trueta and Little (1960) and Trueta and Morgan (1960) the vessels are open

The peripheral vessels of the metaphysis are formed by the periosteal vessels which in this area are called the metaphyseal perforating arteries When these vessels have passed the periosteum of the metaphysis they break up into increasingly smaller vessels which form an anastomosing network in the peripheral metaphysis before they finally form arterioles close to the growth plate which unite with capillaries running to the metaphyseal aspect of the growth plate

There is no difference in the vessels reaching the peripheral part of the metaphysis and those in the central parts Trueta and Morgan (1960) calculated that four fifths of the above mentioned capillaries that reach the growth plate in the proximal tibia in the rabbit derive from the nutrient artery and the remainder from the metaphyseal perforating arteries

The venous vessels which follow after the sinusoids form a central vein which in the middle of the diaphysis unites with the central veins from other areas and leaves the bone marrow cavity through the emissary foramen (Morgan 1959) In addition there are a smaller number of veins that leave the medullary cavity via the nutrient foramen The veins of the metaphysis empty also through anastomoses into periosteal venous plexa

c *The Perichondral Vessels*

Besides the metaphyseal and the epiphyseal vessels there is a vascular system in the perichondrium round the growth plate (Fig 4) This system consists of a circumferential artery which *via* anastomoses intercommunicate with the epiphyseal and the metaphyseal vessels (Morgan 1959 Trueta 1963) The circumferential vessels presumably correspond to the vessels belonging to the perichondral ring of the ossification groove (Morgan 1959) and have therefore been called the perichondral vessels (Hall 1965)

d *Occurrence of Vessels in the Growth Plate*

The growth plate is usually believed to be avascular (Harris 1933 Haraldsson 1959 Trueta and Morgan 1960 Bloom and Fawcett 1962 Irving 1964 Hall 1965 Harris et al 1965) In various species however vessels have been observed in the growth plate prenatally and during the early postnatal growth period As a rule the vessels come from the epiphyseal vessels or from the perichondrium (Weinmann and Sicher 1955 Trueta 1957 Tilling 1958 Brookes 1958 Levene 1964)

Significance of Various Vascular Systems

The significance of the various vascular systems (Fig 4) for the nutrition of the growth plate has been the subject of several investigations The epiphyseal vessels are believed to be responsible for the nutrition of the chondrocytes in the zone of germinative cells and the zone of proliferative cells and probably also for other cartilage cells (Trueta and Morgan 1960 Trueta and Amato 1960 McLean and Urist 1961 Trueta 1963 Salter and Harris 1963 Ham and Leeson 1965 Hall 1965) The parts adjacent to the perichondrium probably receive their nutrition from the perichondral vessels (Brodin 1955 Morgan 1959 McLean and Urist 1961 Irving 1964) On the other hand the metaphyseal vessels are believed not to be of any importance for the nutrition of the cartilage cells but to be important for the endochondral calcification and chondrolysis along the erosion line In addition these vessels are responsible for the nutrition of the cells taking part in the endochondral osteogenesis (Trueta and Morgan 1960 Trueta and Little 1960 Trueta and Amato 1960 McLean and Urist 1961 Salter and Harris 1963 Trueta 1963) Brodin (1955) and Irving (1964) on the other hand claim that the cartilage cells in the growth plate may also receive their nutrition from the metaphyseal vessels

CHAPTER II

METHOD FOR DETERMINING GROWTH IN LENGTH OF THE DIAPHYSIS

A. Survey of Literature

Various methods have been used by different investigators for studying the growth in length of shaft bones. As a rule, macroscopic methods have been used, but microscopical methods have also been applied (see Table I). Most of the methods, however, appear unsatisfactory for one or more of the following reasons:

1. The method does not allow determination of growth in length of the shaft bone from different growth regions.
2. The method allows measurement of growth in length only during periods of several days.
3. The method has traumatic effect on growth.
4. The method has a toxic effect on the growth process in association with intravital marking.
5. The method is not accurate enough for calculation of the growth rate.
6. The method does not allow simultaneous determination of the rate of growth and the morphology of the region of growth.
7. The method is expensive and laborious and its usefulness thereby limited.

Most of the available methods have one or more of the above disadvantages which render them less suitable for the purpose of the present investigation.

It was therefore decided to find out whether it might be possible to measure the growth in length of the diaphysis from the growth plate by intravital staining of the endochondral calcification process with some member of the tetracycline group.

The various tetracyclines[1] have been the subject of thorough investigations regarding their chemical and physical as well as pharmacological properties (Regna et al. 1951, Stephens et al. 1952, English et al. 1953, Boothe et al. 1953, Cunningham et al. 1953, Conover et al. 1953, Dowling 1955, Regna 1955, Lepper 1956, Musselman 1956, Kunin et al. 1959, Kunin and Finland 1961, Spitzy 1962).

The tetracycline molecule consists of a naphthacene ring, which has radicals that vary in a definite way from one member to the other of *the tetracycline group. On comparison with TC it will be found that CTC, like DCTC, contains a chlorine atom while OTC contains a* hydroxyl group. Moreover DCTC lacks a methyl group present in the other tetracyclines.

The tetracyclines are amphoteric compounds in neutral environments and usually not readily soluble. Hydrochloride compound is partly soluble in water but then forms an acid solution which limits its use (Regna et al. 1951, Stephens et al. 1952, Conover et al. 1953, Regna 1955, Spitzy 1962). Therefore various compounds with suitable properties have been manufactured (Spitzy 1962).

Tetracyclines can build compounds with a large number of other substances (Frost et al. 1961 a, Spitzy 1962). They can form complex compounds by chelation with a large number of polyvalent metal ions (Regna et al. 1951, Boothe et al. 1953, Albert 1953, Albert and Rees 1956, Weinberg 1957, Kohn 1961, Ibsen and Urist 1962, Urist et al. 1962a and b, Ibsen et al. 1963) such as Ca^{++}, Mg^{+}, Cu^{+}, Sr^{+}, Fe^{+} and Zn^{++}. The affinity of the various metal ions to the tetracycline group varies. Ca^{+} is said to have a lower affinity than other metal ions occurring in the blood (Urist et al. 1962a). On comparison between the different tetracyclines it has been found that the affinity to the same metal ion varies considerably and it is usually stated that OTC has the lowest affinity (Owen 1963). The stability of the complex compounds varies considerably while the solubility in water is, as a rule, poor in neutral *or basic environments (Weinberg 1957, Ibsen and Urist 1962, Ibsen et al. 1963). The tetracyclines bind* the metal ions in certain proportions (Albert 1953, Albert and Rees 1956, Weinberg 1957, Urist et al. 1962a

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[1] The following abbreviations will be used according to Johnson (1964)

CTC — chlortetracycline
OTC — oxytetracycline
TC — tetracycline
DCTC — demethylchlortetracycline

CHAPTER II

METHOD FOR DETERMINING GROWTH IN LENGTH OF THE DIAPHYSIS

A Survey of Literature

Various methods have been used by different investigators for studying the growth in length of shaft bones. As a rule microscopic methods have been used but microscopical methods have also been applied (see Table 1). Most of the methods, however, appear unsatisfactory for one or more of the following reasons:

1. The method does not allow determination of growth in length of the shaft bone from different growth regions.
2. The method allows measurement of growth in length only during periods of several days.
3. The method has traumatic effect on growth.
4. The method has a toxic effect on the growth process in association with intravital marking.
5. The method is not accurate enough for calculation of the growth rate.
6. The method does not allow simultaneous determination of the rate of growth and the morphology of the region of growth.
7. The method is expensive and laborious and its usefulness thereby limited.

Most of the available methods have one or more of the above disadvantages which render them less suitable for the purpose of the present investigation.

It was therefore decided to find out whether it might be possible to measure the growth in length of the diaphysis from the growth plate by intravital staining of the endochondral calcification process with some member of the tetracycline group.

The above mentioned factors affect the excitation and fluorescence of the tetracyclines to a varying degree. The occurrence of metal ions results in a bathochromic and bathofloric effect (Salzman 1960, Udenfriend et al. 1957, Ibsen et al. 1963). In the presence of Ca^{+} ions this occurs in a characteristic way in that the excitation band becomes narrower and is situated between 4200 and 4600 Å, while the fluorescence band extends between 4800 and 6500 Å. The same change is said to occur when the tetracyclines are dissolved in nonpolar solvents such as carbon tetrachloride and xylol containing substances as mounting agents for histological sections (Frost et al. 1961a).

Helander and Böttiger (Helander and Böttiger 1953, Böttiger 1955a and b) were the first to examine the rate of uptake, distribution, accumulation, retention and excretion in experimental animals with fluorescence microscopy and reported that high concentrations transiently occurred in the reticulo-endothelial system, liver and kidneys. After 3 days only small amounts were found in the bone marrow.

In 1956 the first investigation was published where it was demonstrated that the tetracyclines are bound to bone tissue and the teeth. This examination was carried out by André, who injected tritiated tetracycline into mice and determined the deposition with the autoradiographic method. André showed that in pregnant mice tetracycline passes through the placenta to the bone tissue in the foetus.

Later investigations with fluorescence microscopy have shown that tetracyclines are fixed to tissues undergoing mineralisation (Frost et al. 1961a, Urist and Ibsen 1963, Bevelander 1964, Johnson 1964). Deposition of tetracyclines in association with the ossification process has been the subject of several investigations (Milch et al. 1957, 1958, Rall et al. 1957, Titus et al. 1958, Bevelander et al. 1959a and b, 1960b, Frost 1960a, Frost et al. 1960a and b, 1961a and b, Harris 1960a and b, Muzii 1961, Harris et al. 1962, Hulth and Olerud 1962, Vanderhoeft et al. 1962a and b, Cohlan et al. 1962, 1963, Bevelander 1964, Tapp 1966, Puranen 1966). Deposition in association with endochondral growth has, however, not been studied extensively and the investigations have given varying results (Frost et al. 1960a and b, 1961a and b, Bevelander et al. 1960b, Hulth and Olerud 1962, Coutelier et al. 1963, Urist and Ibsen 1963, Steendijk 1964a and b, Hansson 1964, 1966, Tapp 1966). The ability of callus to bind tetracyclines in association with calcification and ossification of the tissue has received attention (Malek and Kole 1960, Hulth and Olerud 1964).

The deposition of tetracyclines in dental tissue has been extensively

studied and mostly in dentine (Milch et al. 1957, 1958; Rall et al. 1957; Zipkin and Larson 1960; Boyne and Miller 1961; Bevelander et al. 1961; Owen 1961; Gron and Johannessen 1961; Zegarelli et al. 1961).

Degenerating and necrotising tissues undergoing calcification bind large amounts of tetracyclines (Häkkinen 1959; Vassar et al. 1960; Mustakallio 1962). The tetracyclines are also bound to a varying extent to certain types of tumours, presumably to the proteins of the tumour cells (Rall et al. 1957; Loo et al. 1957; McLeay 1958; Milch et al. 1961; Yabe et al. 1964) or to calcium salts in and around the tumour (Vassar et al. 1960; Malek and Kole 1960; Owen 1961, 1965) or in association with resorption of necrotic areas (Vassar et al. 1960; Mustakallio 1962).

The fluorescence of mineralised tissues containing tetracycline is usually yellow, but may vary between orange and green-yellow. There appears to be only a slight difference between the different types of tetracyclines in that the colour of the fluorescence of DCTC is said to be orange, that of CTC to be golden yellow, that of TC yellow, and that of OTC green-yellow (Harris 1960a and b; Harris et al. 1962). These differences are demonstrable only when the tetracyclines are present in high concentration, so that the colour cannot always be regarded as specific of the various tetracyclines (Frost et al. 1961a).

In a large number of investigations the various tetracyclines have been used for intravital marking of the position of calcification process at different times. This method has been used for determining lamellar bone formation (Harris 1960a and b; Frost et al. 1961b; Harris et al. 1962; Hulth and Olerud 1962; Vanderhoeft et al. 1962a; Lee 1963, 1964, 1965; Landeros and Frost 1964; Lee et al. 1965; Tapp 1966) and dentine and enamel formation (Bevelander et al. 1961; Bevelander 1964; Bevelander and Nakahara 1966). The use of the tetracyclines for calculating the rate of endochondral calcification has been proposed by Hulth and Olerud (1962) and has since been used by Hansson (1964, 1966) and Tapp (1966).

In therapeutic and larger doses the tetracyclines can have a toxic effect on the calcification process in cartilage and bony tissue as well as on enamel and dentine, with the result that tetracycline-containing hypomineralised areas may develop (Bevelander et al. 1959a and b, 1960b, 1961; Harris 1960a; Cohlan et al. 1962, 1963; Rolle et al. 1962; Harris et al. 1962; Urist and Ibsen 1963; Owen 1963; Kienitz 1964; Saxen et al. 1964; Lofgren et al. 1965; Omnell et al. 1966). It is claimed

that the toxicity of the various tetracyclines varies and OTC is generally regarded as being least toxic (Harris 1960 a Harris et al 1962 Owen 1963 1965 Chu et al 1964 Kientz 1964 1965) probably because of its affinity for mineralised tissues is low compared with that of other tetracyclines (Owen 1963 1965)

In addition it might be mentioned that when used in small doses the tetracyclines like other substances belonging to the antibiotic group have a stimulating effect on growth (Johnson 1964 Owen 1965) This effect has been demonstrated in experimental animals (Owen 1965) and in children (Jollife et al 1956 Johnson 1964) and is believed to be due to the tetracyclines improving the nutrition in different ways (Owen 1965)

In previous investigations of the deposition of the tetracyclines in mineralised tissues complicated and laborious methods have generally been used for preparing sections for fluorescence microscopy Different types of fixation have been tried such as chemical fixation in formalin methyl and ethyl alcohol (Harris 1960 a and b Plaza Roca 1960 Muzii 1961 Harris et al 1962 Hulth and Olerud 1962) physical fixation by freezing (Milch et al 1957 1958 1961 Hulth and Olerud 1962) and in some cases no fixation (Frost 1960 a and b Frost et al 1960 a and b 1961 a and b Vanderhoeft et al 1962 a and b) In certain cases the preparation was embedded in methyl metacrylate before sectioning (Harris 1960 a and b Muzii 1961 Harris et al 1962 Hulth and Olerud 1962) Various methods have been applied for sectioning such as freeze sectioning (Milch et al 1957 1958 1961) and cutting in a microtome (Bevelander et al 1960b Rolle et al 1962) or in a milling machine (Harris 1960 a and b Harris et al 1962) In several cases the preparation has instead been sawn in slices which were afterwards ground to suitable thickness (Frost 1958 1960 a Frost et al 1960 a 1961 a and b Hulth and Olerud 1962)

B Author s Investigations

1 DEPOSITION OF TETRACYCLINES IN ASSOCIATION WITH ENDOCHONDRAL CALCIFICATION

It is clear from the survey of the literature that the deposition of the tetracyclines in association with the chondral growth process has been studied in only a few usually brief investigations This applies to the

studied and mostly in dentine (Milch et al 1957 1958 Rall et al 1957 Zipkin and Larson 1960 Boyne and Miller 1961 Bevelander et al 1961 Owen 1961 Gron and Johannessen 1961 Zegarelli et al 1961)

Degenerating and necrotising tissues undergoing calcification bind large amounts of tetracyclines (Häkkinen 1959 Vassar et al 1960 Mustakallio 1962) The tetracyclines are also bound to a varying extent to certain types of tumours presumably to the proteins of the tumour cells (Rall et al 1957 Loo et al 1957 McLeay 1958 Milch et al 1961 Yahr et al 1964) or to calcium salts in and around the tumour (Vassar et al 1960 Malek and Kole 1960 Owen 1961 1965) or in association with resorption of necrotic areas (Vassar et al 1960 Mustakallio 1962)

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endochondral calcification as well as the endochondral ossification but the only observations reported on the deposition of tetracyclines in association with perichondral ossification are those published by Hansson (1964).

In the present investigation the deposition of the tetracyclines in association with the endochondral calcification was studied as well as the way in which this deposition is affected by various factors.

Of the various tetracyclines OTC (Terramycin®) was chosen because this compound is regarded less toxic than the other tetracyclines and secondly because it is available in a form suitable for parenteral use.

The following factors were studied for their effect on the deposition of OTC in endochondral calcification:

1. Time, i.e. interval between administration of the drug and sacrifice of the experimental animal.

2. Growth region. The deposition was studied in the growth regions of the tibia, fibula and radius as well as in the distal growth region of the ulna. The investigation thus included both slow and rapidly growing regions.

3. The dose of OTC per kg bodyweight. In the previous investigations the parenteral doses used usually ranged between 10—50 mg per kg bodyweight. In the present investigation large doses of 10 and 25 mg per kg bodyweight were used and relatively small doses of 0.5 and 1.0 mg per kg bodyweight. This wide range was used to find out the suitable dose for further work.

4. The age of experimental animals.

In this investigation only the intravenous route was used because administration by this route produces a rapid transient blood concentration of OTC and thereby deposition which is desired in intravital marking for assessment of growth.

A search was also made for pathological changes which might occur in association with the deposition of OTC. In this investigation it was thought important to use a dose without any definite toxic effect on growth in length.

The methods used previously for preparing sections for examination for deposition of tetracyclines in mineralised tissues were often complicated. This might very well to a great extent explain the discrepancy between the results obtained in the previous investigations of the deposition in association with endochondral calcification. Attempts were therefore made to find out whether it was possible to reduce the number

of sources of error attending preparation of sections for fluorescence microscopy In the present investigation the preparation of the sections was simplified as far as possible including the fixation and the actual sectioning

a *Material*

Previous investigations (Lacroix 1951 Sissons 1953 Brodin 1955 Langenskiold 1957 Tructa and Morgan 1960 Llo 1960 Heikel 1960 Troupp 1961 Rvopps 1965) have shown that rabbits are suitable for the investigation of growth of long bones and these animals were therefore used in the present study In order to obtain an animal series as uniform as possible only white rabbits from a single breeder were used After arrival at the department the animals were observed for a few days The experimental animals were kept together with their mothers both before and during the experimental period Notes were made of the date of birth sex and weight of the animals before and during the experimental period Only young rabbits which weighed more than 250 grams at 20 days and 400 grams at 30 days and appeared normal and healthy were used All animals that fell ill before or during the experimental period were excluded from the investigation The animals were fed on pellets (Lors Ewos) *ad libitum* and roots usually carrots in amounts sufficient for the animal to have a sufficient amount of water The experimental animals were kept in well ventilated room with daylight illumination in fairly large netcages with a floor of network to prevent contact with faeces and urine Average temperature was 16—20°C and relative humidity 40—50 %

The solution of Terramycin®[1] was diluted before used with isotonic saline to suitable concentration In the investigation 4 dilutions were used namely 25 10 1 0 and 0 5 mg OTC per ml solution These dilutions were used for injection for at most 2 weeks during which they were kept like the original solutions in the dark at a temperature of +4°C

The diluted OTC containing solution was given intravenously The rate of injection was 2—4 ml solution per minute The injections were always given at mid day so that any effect of diurnal variation would be the same for all of the animals

Experimental animals were killed at the end of the experimental

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[1] The author is much indebted to Pfizer for kindly supplying the Terramycin® used in this study

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a level of about 10 mm from the growth plate which could be readily identified. When being sawn the bone was held firmly in the region of the diaphysis to protect the ends of the bones from being traumatised. The proximal tibia like the distal tibio-fibula was divided also into a tibial and a fibular half.

FIXATION

Immediately after the preparation the ends of the bones to be examined by fluorescence microscopy were fixed in an abundant amount of absolute ethyl alcohol and thereby also dehydrated. As a rule the fixation period was 12—48 hours, preliminary studies having shown this period to be most suitable.

SECTIONING

After the specimens had been fixed the end regions were cut with a razorblade. The various parts of the end region could be readily identified with the naked eye or under a loupe. Both longitudinal and transverse sections were cut.

Longitudinal sections. In the proximal tibia the sagittal cut surface was used for orienting the frontal section along the longitudinal metaphyseal trabeculae in the central part of the metaphysis. These sections were thus frontal sections in the longitudinal direction of the shaft bone. In the proximal and distal fibula as in the distal tibia corresponding frontal sections were cut in the same way through the central part of the metaphysis. In the proximal and distal radius as well as in the distal ulna the superficial parts were first cut off in a plane parallel to the ulnar surface of the radius and the radial surface of the ulna respectively. It was then easy to cut sections through the central part of the metaphysis and along the trabeculae of the metaphysis, the sections being placed perpendicular to the above mentioned cut surface.

Transverse sections. These sections were taken at various levels of the growth plate and the metaphysis in the proximal tibia. In this case the sections were cut in a plane perpendicular to the central trabeculae of the metaphysis. These transverse sections were used only in the examination of the deposition of OTC in the various parts of the growth region.

The thickness of the sections was determined with the aid of a micrometer of Zeiss Standard microscope by focusing on the upper and

the lower surface of the section The thickness of the longitudinal sections suitable for fluorescence microscopy varied between 10 and 80 μ but most of the sections were about 40 μ

MOUNTING

The sections were then transferred directly to xylol where they were allowed to remain until they were translucent which as a rule took 5—10 minutes The sections were mounted in DePeX (Gurr London) recommended by Mayersbach (1958) The mounted sections were then left for 12—24 hours in faint light after which they were examined under fluorescence microscope

FLUORESCENCE MICROSCOPY

In the fluorescence microscopic examination a conventional binocular microscope was used with Zeiss large fluorescence fitting (Zeiss Oberkochen) The source of radiation consisted of a mercury high pressure lamp of type Osram HBO 200 W As a primary filter a combination of a BG 12/4 and a BG 38/2 5 was used The filter allowed the transmission only of light of wavelength between 3300—5000 Å As a secondary filter a barrier filter 47 was used which allowed the passage only of light of a wavelength longer than 4700 Å In those cases where it was desirable to filter off autofluorescence barrier filter 53 was used In most cases the examination was made with the aid of a dark field condensor (NA 0 65/0 85) together with planachromatic objective with 6.3× (NA 0 16) and 10× (NA 0 22) magnification To obtain higher magnification use was made of a planachromatic objective 16× (NA 0 32) and 25× (NA 0 45) magnification with a dark field condensor with NA 0 85/0 95

On some occasions an ordinary light field condensor with a wide open diaphragm was used together with planachromatic objectives 2 5× 6 3 and 10× In this combination the secondary filter was as a rule a barrier filter 53 to filter off direct light from the lamp with a wavelength of less than 5300 Å C8× or C12× was used as ocular

In the length measurement in the microscope use was made of an ocular Kpl 12 5 equipped with a micrometer 10 mm long and graduated into 100 parts This micrometer was used together with a planachromatic objective 10 (NA 0 22) and was calibrated with the aid of an objective micrometer (Reichert) in such a way that every part on the scale corresponded to 10 μ

The above mentioned microscope was fitted with a camera (24× 36 mm). For microphotography the same objectives were used and the same condensors as those described previously and as ocular Kpl 8×. For colour photos Ektachrome EHB 135/20 (Kodak) was used and for photography in black white Scientia 50 B 65 (Gevaert).

c. *Results*

GENERAL

In the fluorescence microscopic examination of the growth area in normal non treated animals autofluorescence of varying intensity and colour was noted. In areas without signs of calcification this autofluorescence was different shades of blue.

In areas with cartilage matrix containing calcium salts as in the growth plate and the metaphyseal trabeculae the autofluorescence was much more intense and blue white or pale blue. The autofluorescence in the bony tissue in the metaphysis was less intense and clear blue with blue white streaks. Many cells in the cartilaginous growth zone were seen because of the light blue autofluorescence of the nuclei which were surrounded by dark blue fluorescent cytoplasm.

In animals that had received OTC the normal autofluorescence was seen only in certain areas. The other parts showed secondary fluorescence[1] with varying intensity because of its content of OTC.

In some of the areas the fluorescence was intense and golden yellow while in others it was faint and green yellow.

The fluorescing OTC thus occurred in varying concentration in different parts of the growth regions of the shaft bone.

1. A very large amount was deposited in the cartilage matrix in association with the endochondral calcification process in the end regions of the shaft bone.
2. In the diaphysis and bony epiphysis OTC appeared in varying concentration in association with the endochondral ossification.
3. The perichondral ossification process bound large amounts of OTC.
4. Distinct fluorescence was observed on the surfaces undergoing lacunar resorption.

[1] In what follows fluorescence is to be understood as secondary fluorescence.

5. In addition diffuse and weak fluorescence was often seen in older bony tissue and in superficial parts of the periosteum perichondrium and joint cartilage.

In what follows only the deposition of OTC in association with the endochondral calcification process will be discussed. The rest of the deposition is not discussed because it is not necessary for determination of the growth in length of the diaphysis.

DEPOSITION IN ASSOCIATION WITH THE ENDOCHONDRAL CALCIFICATION

The following section deals with the deposition of OTC in different growth regions and at different intervals after the injection. The animals that were used for this investigation were 5—6 weeks old at the beginning of the experimental period.

Deposition in Different Growth Regions and at Different Intervals after Intravenous Injection of 25 mg OTC per kg Bodyweight

Proximal Tibia

1 minute

The injected fluorophore was observed already 1 minute after the beginning of the intravenous injection in a band situated largely within the growth plate and partly in the adjacent part of metaphysis (Figs. 5, 9). The fluorescent band was 120—160 μ wide. The metaphyseal front was well defined and either coincided with the line of erosion or ran parallel to that line in the metaphysis at a distance of at most 40 μ from the growth plate. The front of the fluorescing band closest the perichondral region was situated further in the metaphysis but as a rule at most 80 μ.

The intensity of the fluorescent band was highest in a roughly 50 μ wide area in that part situated closest to metaphyseal front and the fluorescence was intense golden yellow. In those parts closer to the epiphysis the colour of the band gradually became paler yellow and in the most epiphyseal parts it was pale green yellow. The metaphyseal border of the fluorescent band was thus sharply defined while its epiphyseal border was diffuse and difficult to identify. Epiphyseally to the band in the growth plate and metaphyseally to the band in the cartilaginous part of the metaphyseal trabeculae there was normal autofluorescence.

The yellow fluorescence in the fluorescing band was due to the OTC content of cartilage matrix in both longitudinal and transverse septa (Fig. 7). No deposition was found with certainty in the cartilage cells which usually showed pale blue autofluorescence of the nucleus and dark blue autofluorescence of the cytoplasm. The largest amounts of OTC were found in the longitudinal septa and especially in those parts connected with the transverse septa. The most intense fluorescence was seen in the periphery of the septa adjacent to the cartilage cells. The fluorescence in the central parts of the septa was, as a rule, faint but showed wide variations.

In the narrowest longitudinal septa the central less strongly fluorescent part was often so narrow that it appeared as if the intensely fluorescing more peripheral parts joined one another.

In the broader longitudinal septa no signs of deposition of OTC were found in the central parts of the septa and particularly when this central part was widened, which was the case in those parts adjacent to the transverse septa. This central area was, as a rule, narrowest in the most metaphyseal part of the band and continued into the autofluorescing cartilaginous part of the trabeculae of the metaphysis. In the more epiphyseal parts the central area became broader at the same time as the more peripherally situated parts of the fluorescing septa became narrower and less fluorescent.

In the transverse septa there was also yellow fluorescence but of much lower intensity than that in the longitudinal septa. Moreover these septa were thinner than the longitudinal septa so that the intensity appeared to be the same in the entire septum. In the area where the septa were in connection with the longitudinal septa the fluorescent line divided Y-shaped and the two limbs continued directly in the intensively fluorescing parts in the longitudinal septa. These fluorescing transverse septa occurred only in the most metaphyseal part of the growth plate.

The fluorescent band comprised 4—8 cartilage cells situated closest to the metaphysis in each column of cells. Of these cells 2—5 situated close to the metaphysis in each column were surrounded entirely by fluorescent cartilage matrix in both the longitudinal and the transverse septa. The other more epiphyseally located cells were outlined only by fluorescing cartilage matrix in the longitudinal septa.

In those parts of the growth plate which were adjacent to the perichondral ring yellow fluorescence was seen in the cartilage matrix further in the growth plate than in other areas in both longitudinal

and transverse septa and the fluorescence often appeared to be most intense near this bony lamella. The result was that many cells in the columns adjacent to the perichondral region were partly or entirely surrounded by fluorescent cartilage matrix.

2—15 minutes

During the next few minutes the fluorescence appeared to be the same as after one minute. During this period the fluorescence increased in intensity and appeared to reach a maximum at the end of this period. Then the metaphyseal front of the band was more marked than before.

30 minutes—6 hours

The fluorescent band became increasingly wider during the following 6 hours. Its metaphyseal border which just after the injection was at the border between the growth plate and the metaphysis, was situated further down in the metaphysis. This was possible to observe because of, among other things, the metaphyseal vessels which extend to the line of erosion were brown and readily identified, especially in the area adjacent to the growth plate.

It was therefore possible to ascertain that one hour after injection the metaphyseal front of the fluorescent band was some tens of microns further from the growth plate compared with the position just after the injection. Three hours after the injection the distance was 60—80 μ and after 6 hours 120—150 μ.

As before the fluorescence was most intense in the most metaphyseal part of the fluorescent band while it decreased gradually in the epiphyseal part. The strongest fluorescent part during this period became some tens of microns wider.

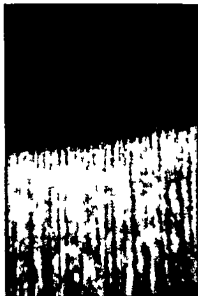
The maximal width was noted about 3 hours after the injection. Also the epiphyseal less fluorescent part of the band became broader.

Fig. 5. Localisation of OTC in association with endochondral calcification 1 minute after intravenous injection of 25 mg per kg bodyweight. Section from proximal tibia (60 ×).

Fig. 6. Localisation of OTC in association with endochondral calcification 12 hours after intravenous injection of 25 mg per kg bodyweight. Section from proximal tibia (60 ×).

Fig. 7. Localisation of OTC in association with endochondral calcification 10 minutes after intravenous injection of 10 mg per kg bodyweight. Section from proximal tibia (1[illegible]0 ×).

Fig. 8. Localisation of OTC in association with endochondral calcification 24 hours after intravenous injection of 25 mg per kg bodyweight. Pathological changes in fluorescent band. Section from distal ulna (60 ×).









8

Six hours after the injection the metaphyseal front of the band was situated about 160 µ from the line of erosion. Some time between 6 and 12 hours after the injection the band was situated entirely in the metaphysis. The fluorescent band was then most often only 120—150 µ broad with a roughly 60 µ broad intensely fluorescent area. The distance between the front of the band and the growth plate increased with time. One day after the injection it was about 580 µ (Fig. 10) and 4 days after the injection about 2100 µ.

Three to four days after the injection large parts of the fluorescent band were resorbed in association with expansion of the bone marrow cavity. Since also the peripheral parts adjacent the periosteum were gradually resorbed there remained only two short parts of the fluorescent band on each side of the bone marrow cavity.

Also in the distal ulna there was a weak green yellow fluorescence at most 100 µ broad in the metaphyseal part of the growth plate and in the cartilaginous matrix of trabeculae in the adjacent part of the metaphysis, although the fluorescent band was situated further in the metaphysis. That part situated in the metaphysis was obscured from view partly by the metaphyseal vessels and therefore appeared weaker than the part in the growth plate.

Proximal Fibula, Distal Tibio-Fibula and Distal Radius

The deposition of OTC in these regions showed several features in common and will therefore be dealt with together.

The fluorescent band which developed as in the previously mentioned regions immediately after the injection appeared to be confined to the metaphyseal part of the growth plate. The metaphyseal front seemed to coincide with the erosion line. In the area adjacent to the perichondral ring the front was often situated some tens of microns inside the metaphysis. The fluorescent band in the various growth zones the first few minutes after the injection were between 100—120 µ broad and their fluorescence was most intense in an area 40—50 µ broad nearest the metaphysis and then became fainter towards the epiphysis where it ceased with a diffuse outline (Fig. 9).

The deposition of OTC in the cartilage matrix was the same as in the proximal tibia, thus largely in the longitudinal septa and only to a small extent in the most metaphyseal transverse septa in each cell column.

During the first hours after the injection the fluorescent band became broader and its front became situated further into the metaphysis. Six hours after the this front was 100—110 µ in the meta

physis. In the band the most metaphyseally situated part showed the strongest fluorescence and was about 60 μ broad. The epiphyseal outline was diffuse and difficult to determine but appeared to extend 50—100 μ into the growth plate. The fluorescent band in these growth zones lost contact with the growth plate between 6 and 12 hours after the injection as in the proximal tibia.

The breadth of the various fluorescent bands then remained constant between 100—120 μ and were much narrower than 6 hours after the injection. As before, the weakly fluorescent part of the band which tapered, while the intensely fluorescent band, as before, was 50—60 μ broad.

The distance between the front of the band and the line of erosion increased by 420—460 μ per day (Fig. 10) varying somewhat from one experimental animal to another. This distance was as a rule largest in the distal radius, somewhat less in the proximal fibula and smallest in the distal tibio-fibula on comparison between the various growth zones in one of the animals.

Large parts of the fluorescent band were resorbed entirely or partly according to the same pattern as that described previously. Resorption of the middle part of the fluorescent band usually occurred 3—5 days after the injection.

During the period when the fluorescent band was situated entirely in the metaphysis there was usually a weak green-yellow fluorescence in the metaphyseal part of the growth plate, as a rule 60—80 μ broad. This weak fluorescence was of the same type in all of the above-mentioned growth zones.

Proximal Radius

1—15 minutes

Within one minute after the injection large amounts of OTC were deposited in the growth plate of the proximal radius in the metaphyseal part. Here too an intensely fluorescent band developed with golden-yellow colour whose intensity increased during the following minutes. The band was situated inside the growth plate, separated entirely from the metaphysis in contrast to what was seen in the other regions studied. The fluorescing band was 30—60 μ broad and was separated from the metaphysis by a 10—30 μ broad area with autofluorescence (Fig. 9).

The fluorescing band was most intense in the most metaphyseal part in a 20 μ broad band while the yellow fluorescence in the rest of the fluorescing band decreased relatively rapidly in epiphyseal direction.

The metaphyseal front of the band was sharply outlined and was more sharply defined than in the proximal tibia

The largest amount of OTC containing cartilage matrix was found in the longitudinal septa and especially in the peripheral parts of the septa In the metaphyseal part of the fluorescent band there was also deposition in a few transverse septa 1—2 of the cells in each cell column and always the most metaphyseally situated ones were outlined by golden fluorescent transverse septa In the areas adjacent to the perichondral ring the fluorescent band approached the metaphysis and furthest out to the perichondral ring the metaphyseal vessels extend a short distance into the band but as a rule at most 20 μ

30 minutes—12 hours

During the first few hours the fluorescent band became broader and the autofluorescent area situated between the band and the metaphysis became narrower and finally disappeared Three hours after the injection this area had disappeared and had been replaced by intense golden yellow fluorescence at the same time as the intensely fluorescent part had become about 20 μ broader than just after the injection Six hours after the injection the front of the fluorescing band was situated in the metaphysis and about 20 μ from the growth plate The stronger fluorescent part extended about 10 μ into the growth plate The total breadth of the fluorescent band appeared to be about 60 μ and its epiphyseal border was more diffuse and more difficult to delineate than before At 12 hours after the injection the front of the band was situated about 10 μ in the metaphysis The largest part of the band was then inside the metaphysis while a minor part some tens of microns in breadth was situated within the growth plate adjacent to the metaphysis That part of the fluorescent band that was situated in the metaphysis fluoresced much weaker than before because of the brown coloured metaphyseal vessels which obscured the OTC containing cartilaginous trabeculae

1 8 days

Between 12 and 24 hours after the injection the fluorescent band lost contact with the growth plate and was then situated entirely in the metaphysis The fluorescent band on that occasion was between 40—60 μ broad and did not vary appreciably in breadth during the following period One day after the injection the distance between front of the fluorescent band and the line of erosion was about 100 μ (Fig 10)

This distance appeared to increase by about 100 μ per day in the experimental animals and was for example 4 days after the injection 420 μ

As previously mentioned in the description of the other growth zones large parts of the fluorescent band were resorbed entirely or partly when it was situated within the metaphysis The expansion of the bone marrow cavity in epiphyseal direction resulted in the middle part of the fluorescent band disappearing entirely within 6 days after the injection In addition the peripheral parts were resorbed in association with the narrowing of the metaphysis

In those cases where the fluorescent band was situated within the metaphysis small amounts of OTC were sometimes also seen in the growth plate Also in these cases autofluorescence occurred in the growth plate adjacent to the metaphysis Autofluorescence also occurred in the cartilage matrix in the trabeculae situated both diaphyseally and epiphyseally to the strongly fluorescent band in the metaphysis in the same way as in the proximal tibia

Deposition after Intravenous Injection of Various Amounts of OTC

In the preceding sections the deposition of OTC at a varying interval after intravenous injection of 25 mg OTC per kg bodyweight was discussed Below an account is given of the deposition of OTC 10 minutes and 24 hours after intravenous injection of a varying amount of OTC The appearance of the fluorescent band in the proximal tibia was studied after injection of the following doses 25 10 1 0 and 0 5 mg OTC per kg bodyweight

10 minutes

Administration of the dose was always followed by the appearance of a band situated largely within the metaphyseal part of the growth plate and to a certain extent in the adjacent part of the metaphysis The fluorescent band which appeared after 25 mg per kg was 120—160 μ broad while the breadth after injection of 10 mg per kg appeared to be some tens of microns less The corresponding breadth of the band after 1 0 and 0 5 mg per kg bodyweight was 80—100 μ The metaphyseal front of the fluorescent band appeared to be identical after all doses but not the epiphyseal border The metaphyseal border of the fluorescent band was more distinct when the dose was large than when it was small

The intensity of the fluorescence was highest after injection of 25 mg per kg and weakest after 0 5 mg per kg bodyweight and irrespective of

the size of the dose it was always most intense in the metaphyseal part and decreased in epiphyseal direction.

The colour in the most metaphyseal part of the band after injection of 25 mg per kg was intense golden yellow and after 10 mg per kg somewhat paler yellow. After smaller doses 1.0 and 0.5 mg per kg the colour was pale yellow respectively green-yellow and the fluorescence after the latter dose decreased and almost disappeared in a few minutes. The corresponding difference in intensity and colour occurred also in the epiphyseal part of the fluorescent band.

24 hours

The fluorescent band was now situated far in the metaphysis after all doses. The distance between the front of the band and the line of erosion was always between 500—510 μ but the breadth of the band varied widely. After 25 mg per kg the breadth was 120—150 μ and after 10 mg per kg it was 100—120 μ. The fluorescent band appearing after the small doses was much narrower and was between 30—60 μ and appeared to be somewhat broader at 1.0 than at 0.5 mg per kg.

The difference in intensity and colour with the various doses appeared to be about the same as just after the injection. The more strongly fluorescing part of the band appeared to have increased by some tens of microns in breadth after 25 mg per kg, while its breadth after injection of the smaller dose 0.5 mg per kg was the same as immediately after the injection. The epiphyseal border of the fluorescent band after all doses and especially after small doses was more difficult to recognise than immediately after the injection.

The part of the metaphysis which was situated in the fluorescent band and the line of erosion was much narrower after 25 mg per kg than after 0.5 mg per kg. In this area blue or blue-white autofluorescence was seen in the cartilaginous parts of the trabeculae. This autofluorescence occurred after all doses in that part nearest the line of erosion and extended furthest into the metaphysis after a small dose because the fluorescent band was then much narrower than after injection of a large dose.

In the metaphyseal part of the growth plate small amounts of OTC were seen after injection of all doses.

Variation of Deposits of OTC with Animal's Age

In the previous section an account was given of the deposits of OTC at an age of 5—6 weeks as well as the effect of various factors on the

deposition In what follows the effect of age on the deposition after an intravenous injection of 1 0 mg OTC per kg body weight is discussed in association with the endochondral calcification process in the proximal tibia

10 minutes

The fluorescent band was much broader in animals 20—30 days old than in older animals In 20—30 day old animals the breadth was about 120 μ compared with 60 μ in 70 day old animals This also applies to the more brightly and less brightly fluorescent part of the band The more brightly fluorescent part in the younger animals was about 70 μ against only 30 μ in 70 day old animals The weak fluorescent part decreased also with age but only by some tens of microns during the entire period

As previously mentioned the fluorescent band extended up to 40 μ into the metaphysis at 5—6 weeks of age In young animals this was more pronounced and at 20 days of age the fluorescent band usually extended 30—50 μ metaphyseally on the erosion line On the other hand the fluorescent band as a whole was situated in the metaphyseal part of the growth plate at 60—70 days of age and then its front coincided with the erosion line In addition the metaphyseal front appeared to be better outlined with age which to a certain extent holds also for the epiphyseal outline of the band

Also the intensity of the fluorescent band changed with age The intensity at 20 days of age was relatively low and in some animals it was difficult to record photographically The intensity increased with age and particularly between 20 and 40 days It was highest at 70 days when the colour of the fluorescent band was clear yellow compared with weak green yellow at 20 days in the strongest fluorescent part

Changes of the same type were seen in other growth zones studied with the result that the fluorescent band became narrower with increasing age and more strongly fluorescent at the same time as its metaphyseal border shifted in epiphyseal direction

24 hours

The observations described above were also made 24 hours after the injection Thus the breadth of the fluorescent band decreased with age It was about 80 μ at 20 days and 50 μ at 70 days in the proximal tibia This decrease was caused mainly by the fact that the more strongly fluorescent part which occupied the major portion of the band diminished with increasing age while it was not possible to observe any

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corresponding decrease of the weakly fluorescing part since it was only 10—20 μ broad during the period of life covered by the investigation.

The position of the fluorescent band changed with age and with time was situated closer to the growth plate. The distance between the front of the fluorescent band and the erosion line at 30 days of age was about 590 μ against about 400 μ at 70 days. On the other hand this distance appeared to be somewhat shorter at 20 days than at 30 days.

The intensity of the fluorescent band which at 24 hours appeared to be slightly stronger than at 10 minutes after the injection increased with age in the way described previously.

The above mentioned changes in the breadth, position and intensity of the fluorescent band were observed also in the other growth zones examined. It should be mentioned that the fluorescent band in the proximal radius in some animals aged 60—70 days was 24 hours after the injection still situated entirely or partly within the growth plate which was not the case in other growth zones studied.

Pathological Changes

In the growth zones in the animals that had received OTC intravenously in a dose of 25 mg per kg bodyweight deviations from the normal appearance of the metaphysis and the growth plate were often seen a short time after the injection.

The appearances of the changes seen in the proximal tibia are described below. It should however be mentioned that corresponding changes occurred also in other regions studied.

As a rule the changes made their appearance at the earliest during the first hour after the injection in the strongest fluorescent part of the band at the border between the metaphysis and the growth plate. The appearance of the changes varied considerably. The slightest changes occurred in the form of slight bending of the OTC containing cartilaginous trabeculae in the most fluorescent part of the band. When the changes were severe the cartilaginous trabeculae were interrupted in the fluorescent zone (Fig. 8). In addition especially when the changes were severe the epiphyseal and diaphyseal parts of the cartilaginous trabeculae were displaced to a varying extent in relation to one another both transversally and longitudinally. The result was that the fluorescent band in the area with these changes was often narrower than in adjacent normal areas and the breadth of the fluorescent band was sometimes only half of normal. In areas with these changes this

was generally most pronounced in the central part peripherally the changes decreased diffusely and disappeared In some cases changes were seen in all parts of the fluorescent band

The severest changes in a growth zone were often closest to the perichondral ring In this region the epiphyseal parts of the cartilaginous trabeculae were usually displaced in direction towards the perichondral lamella in relation to the diaphyseal parts of the trabeculae This shift of the cartilaginous trabeculae was more pronounced in those parts where the trabeculae converged in diaphyseal direction than in those parts where the trabeculae ran more or less parallel to the central trabeculae In some cases the part of the perichondral ring which was situated epiphyseally to the fluorescent band was displaced peripherally in relation to the diaphyseal part

In the growth zone of the proximal tibia crude changes were also seen in the central part In this part the change often consisted of a change in the longitudinal direction of the trabeculae and sometimes though rarely in transverse direction

In other parts of the fluorescent band between the area adjacent to the perichondral ring and the central area there were rarely any changes In those cases where changes were seen they consisted of curving and compression of the cartilaginous trabeculae

The above mentioned changes developed as mentioned above already during the first few hours after the injection Both the normal and the changed cartilaginous trabeculae in the fluorescent band were covered by bony tissue on the first day On the following days parts of the band were resorbed within both the normal and the changed part Within the remaining parts of the band changed cartilaginous parts were often seen in the metaphyseal trabeculae at the end of the experimental period

In the area with severe changes changes were seen on the first day after the injection which were probably secondary to changes within the band (Fig 11) In the area with curved and broken cartilaginous trabeculae an autofluorescent tongue of cartilage cells from the growth plate was seen In adjacent areas where the fluorescent band appeared to be normal no corresponding cartilage cells were seen The tongue of cartilage cells during the first few hours after the injection was often rectangular but later after it had increased further in length it became more and more triangular with the apex pointing in diaphyseal direction This was because the tongue of cartilage cells was resorbed in the peripheral parts which was marked in the area closest to the



Fig. 11 A. Pathological changes in form of curved and broken metaphyseal trabeculae and a tongue of cartilage cells extending into metaphysis 24 hours after intravenous injection of 10 mg OTC per kg bodyweight. Paraffin section (about 10 μ) from proximal tibia from decalcified material fixed in Bouin's fluid. Haematoxylin-eosin according to Ehrlich (0×)

fluorescent band. The remaining triangle was then broken down in epiphyseal direction and replaced by metaphyseal trabeculae with intermediate vessels. The tongue of cartilage cells therefore often disappeared 1—2 days after the injection. The metaphyseal trabeculae which replaced the central parts of the cartilage tongue often ran in a largely straight line, while the more peripheral trabeculae closest to the fluorescent band converged towards the centre and further epiphyseally again became straight.

Occasionally it was observed a few days after the injection single or small clusters of cartilage cells epiphyseally to and adjacent to the fluorescing band in the area with severe changes. In addition the metaphyseal vessels in this area ran more irregularly than in cases with slight changes. In the area with slight changes the metaphyseal vessels were traced through the fluorescent band right to the most metaphyseal cartilage cells in the growth plate. In the area with pronounced changes the metaphyseal vessels ran to the fluorescent

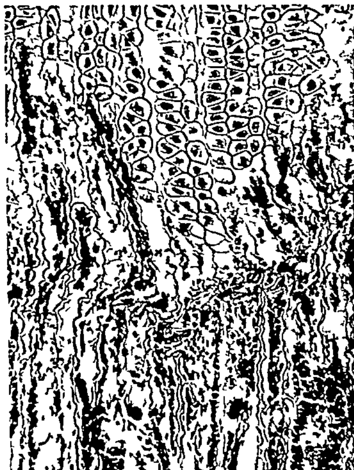


Fig 11 B Higher magnification of area with pathological changes in Fig 11 A (155×)

band Further epiphyseally between the cartilage cells adjacent to the fluorescent band and the remaining part of the tongue of cartilage cells were brown metaphyseal vessels which appeared to be in communication with the metaphyseal vessels in the adjacent areas

In the investigation of the frequency of the pathological changes it was found that the growth zone of the proximal tibia showed signs of pathological changes of varying severity in all 15 animals killed 24 hours after the injection of 25 mg OTC per kg bodyweight In some animals the changes dominated and in others they were seen in only a small part of the fluorescent band In the present material were 4 cases with only slight curving of the cartilaginous trabeculae 6 with severe bending and 5 with pronounced changes with bent and broken trabeculae

In 15 experimental animals which had been given 10 mg OTC intravenously and were killed 24 hours after the injection the frequency and the severity of the changes were lower. In 11 of these animals there were no signs with certainty while a slight effect was noted in 4 animals.

In 15 experimental animals which had been given 1.0 mg OTC changes in the form of deformed trabeculae occurred in 1 case. These changes were confined to a small area adjacent to the perichondral lamella.

The occurrence of changes one day after an intravenous dose of 0.5 mg OTC was studied in the same way in a similar series of 15 experimental animals. In these animals the proximal tibia showed no changes with certainty.

Changes occurred also in the other growth regions studied after intravenous injection of 10 and 25 mg OTC per kg bodyweight. As in the proximal tibia the changes appeared to be located primarily in the most fluorescent part of the band.

The changes were, as a rule, somewhat more common in the distal ulna than in the proximal tibia. Similar changes also occurred in the distal tibio-fibula and proximal radius but were not so common or so severe as in the former regions. Such changes were seldom seen in the proximal fibula and distal radius.

It was also observed that in those cases where changes occurred in a growth zone similar changes occurred in most cases also in the growth zone on the contralateral side.

d. *Discussion*

Previous methods used for the production of sections for fluorescence microscopic examination of the deposition of the tetracyclines in the growth regions of the shaft bone have usually been more complicated and laborious than the one used here. In the present investigation it proved possible to simplify the fixation, dehydration and sectioning and to exclude embedment of the preparation, apparently without introducing new sources of error.

It has previously been shown that the results of the examination depend to no small extent on the method of fixation used. Hulth and Olerud (1962) observed on comparison of different fixation methods that freeze fixation combined with freeze drying, like fixation in absolute methyl or ethyl alcohol for 1—2 days does not cause any demon

strable dissolution of bound tetracyclines which however occurs on fixation in aqueous solutions It has also been shown that long fixation periods in aqueous fixatives as well as in absolute methyl or ethyl alcohol results in increased dissolution of tetracyclines bound to mineralised tissues (Frost 1960 a Frost et al 1960 a and b Mazu 1961) and secondly that the risk of dissolution is greatest during the first few days after the injection when tetracyclines are believed to be less firmly bound than later (Frost et al 1960 a 1961 a Hulth and Olerud 1962)

In the present investigation however it was observed that also fixa tion in absolute ethyl alcohol can give rise to dissolution of bound tetracyclines since green yellow fluorescence is seen in the zone of cartilage undergoing calcification in spite of the fact that several hours and days have elapsed between the injection and the sacrifice of the animal Similar green yellow fluorescence has previously been observed by Harris et al (1962) and Lee (1963 1965) in the zone of calcification in lamellar bone formation but they considered this fluorescence not to come from deposited tetracyclines but instead to be identical with the autofluorescence of osteoid tissue The reason why this deposition is believed to be largely postvital is that the cartilaginous tissues which are situated between the zone of cartilage undergoing calcification and the intensely fluorescent band in the metaphysis usually contain no demonstrable amounts of tetracyclines which they should if the above mentioned deposition had occurred intravitally The postvital deposition is probably also the reason why the fluorescent band is somewhat wider some hours after the injection than later when the band is situated *in* the metaphysis It is also probable that the *diffuse occurr* ence of tetracyclines like their deposition in the form of surface stain in bone tissue (Ghosez 1959 Ponlot 1959 Frost et al 1960 b 1961 a Harris 1960 a Harris et al 1962 Hulth and Olerud 1962 Steendijk 1964 a and b Tapp et al 1965) occurs largely postvitally

As the degree of mineralisation in the cartilaginous and osseous trabeculae is very high (Pritchard 1961) it is not probable that the fixation in absolute ethyl alcohol causes shrinkage of the mineralised tissue of the growth zone On the other hand the fixation causes appreciable shrinkage of the non mineralised tissues (Romeis 1948 Baker 1955 Burck 1966)

At the same time as the preparation is fixed in absolute ethyl alcohol it undergoes dehydration so that it need only be placed in a single

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In the present investigation the fluorescence does not appear to change in colour or intensity after mounting of the sections. This does not corroborate the finding of Boiko (1959) and Frost et al. (1960 a and b). In their investigations the changes were probably due to the fact that the sections were mounted without previous dehydration. It has previously been shown that the fluorescence of tetracyclines is quenched and becomes more shortwaved in polar and aqueous solvents but on the other hand not in nonpolar and nonaqueous solvents such as xylol and various xylol containing mounting compounds (Frost et al. 1961 a, Hattner and Frost 1962). On the other hand it was observed that the resolving power during fluorescence microscopy increases the first few hours after the sections have been mounted which is probably due to the penetration of the mounting compound into the section.

For various reasons it was apparent in the present investigation that OTC is deposited in the endochondral calcification process in a well defined band. The deposition agrees well with the area of deposition of the radioactive isotopes Ca^{45} (Ponlot 1959, Lacroix 1960 a and b, 1962) and P^{32} (Leblond et al. 1950, Leblond and Greulich 1961) which are deposited in the zone of cartilage undergoing calcification. In the broad longitudinal septa the deposition of OTC agrees with the results obtained in electron microscopic examinations of the endochondral calcification process by Robinson and Cameron (1956), Scott and Pease (1956) as well as by Takuma (1960) while the deposition in the narrow longitudinal septa agrees with the assumption of Durning (1958) and Trueta and Little (1960). The somewhat varying deposition in the longitudinal septa is therefore an expression of the normal variation in a growth region. The differences in opinions may be due to the use of material from different growth zones, species and animals of different ages in the previous investigations referred to above.

The deposition of OTC in the transverse septa is, as is apparent from the results, much less than that in the longitudinal septa. This agrees well with previous investigations (Bloom and Bloom 1940, McLean and Bloom 1940, Lacroix 1951, Scott and Pease 1956, Durning 1958, Trueta and Little 1960) which were performed with different methods. The reason why Dodds (1932) and Dodds and Cameron (1934) were unable to find signs of deposition of calcium salts may be due to the sensitivity of the method used having been too low. It might also be an expression of a normal variation because Robinson and Cameron (1956) were

Frost (1961). Urist and Ibsen (1963) like Steendijk (1964 a and b) claimed that the tetracyclines are deposited in the growth plate while Milch et al. (1957, 1958, 1961), Bevelander et al. (1960 b) like Holmes (1963) stated that normally no deposition occurs in the growth plate but that deposition of large amounts of tetracyclines occurs in the adjacent part of the metaphysis. According to Hulth and Olerud (1962) the largest amounts of tetracyclines are deposited in the metaphysis nearest the growth plate while small amounts are deposited in the cartilaginous matrix in the growth plate. They stated, however, that the former deposition is not related to the endochondral calcification but to the activity of the osteoblasts in this region. Similar deposition partly in the growth plate and partly in the metaphysis has also been observed by Coutelier et al. (1963) but they claimed that the deposition in the two areas is related to the endochondral calcification process.

On closer analysis of these investigations it was realised that the experimental animals in some of the studies (Holmes 1963, Coutelier et al. 1963) have not been sacrificed until several hours after the injection of the tetracyclines so that the localisation of the tetracyclines in these cases does not correspond to the zone of cartilage undergoing calcification. The reason why Milch et al. (1957, 1958, 1961) found no deposition in the growth plate under normal conditions but fluorescent tetracyclines in the cartilaginous matrix in an osteochondroma is difficult to understand. The light bluish gray fluorescence they observed in the metaphyseal part of the growth plate was interpreted as autofluorescence. This finding might depend on too long an interval between the injection and sacrifice of the experimental animals with the result that these observations do not apply to the zone of cartilage undergoing calcification. It may also be due to the sections not being adequately dehydrated. The reason may also be that the above mentioned investigations were carried out in the growth zone of the distal femur which belongs to one of the most rapidly growing regions and if so the area with bluish gray autofluorescence would correspond to the epiphyseal and faintly fluorescent part of the fluorescent band. It is also conceivable that the method for preparing the sections influenced the deposition in such a way that the bound tetracycline was dissolved since the tetracycline is initially only very loosely bound (Frost et al. 1960 a, 1961 a, Hulth and Olerud 1962). In addition Milch et al. (1957, 1958) stated that only occasional sections were satisfactory for histological examination owing to fragmentation of the specimen which may be due to the freeze fixation and freeze sectioning method used, which

surely caused difficulties and influenced the localisation of the deposited tetracycline. The varying deposition of the tetracyclines in the endochondral calcification process in the other investigations (Frost et al. 1960 a and b, 1961 a and b, Bevelander et al. 1960 b, Frost 1961, Hulth and Olerud 1962, Urist and Ibsen 1963, Steendijk 1964 a and b) can probably be explained in part by the fact that these investigations were carried out in different growth regions in animals of different ages and in material from different species. The method for preparing sections may also have influenced the possibilities of localising the fluorophore.

During the first few minutes after the intravenous injection of OTC it was observed that the intensity in the most intense part of the fluorescent band increased and after at most half an hour it reached its maximum value. At the same time the colour changed and became more yellow. This was presumably because the OTC concentration in the cartilaginous matrix increased and reached its maximum during the latter part of the above mentioned period.

During the following hours after the injection the fluorescent band became wider because the endochondral calcification process continuously moved in epiphyseal direction. The tetracyclines continued to be deposited in the zone of cartilage undergoing calcification as long as there were circulating tetracyclines in the blood. It was found that the deposition after intravenous injection of 25 mg OTC per kg bodyweight almost stopped after 3—6 hours, while the deposition after smaller doses ceased earlier. This was because the smaller doses produced a lower blood concentration and were eliminated earlier from the blood than the larger doses (Buyske et al. 1960, Kelly and Buyske 1960).

After the above mentioned period only slight vital deposition of tetracyclines occurred in the zone of cartilage undergoing calcification. The fluorescent band has then reached its final width. The fluorescent band becomes localised more and more metaphyseally during the following periods. This is because the zone of cartilage undergoing calcification like the growth plate shifts in epiphyseal direction, while the fluorescent band is situated at the same site the whole time because the tetracyclines are bound to the mineralised cartilaginous matrix. It was found that the fluorescent band looses contact with the growth plate at different times after injection in different growth regions. In the growth regions with high rate of growth as in the distal ulna and the proximal tibia it occurs much earlier than in the growth zones with slow rate of growth such as proximal radius

because of the difference in position of the calcification zone in relation to the line of erosion

The fluorescent band becomes fainter to a certain extent with time which is due to the resorption processes in the metaphysis It was observed that the fluorescent band comes into contact with the bone marrow cavity after 3—6 days in the different growth zones which suggests that the distance between the growth plate and the bone marrow cavity is related to the rate of the endochondral growth process (Lacroix 1951 Sissons 1953)

After deposition of the tetracyclines in the zone of cartilage undergoing calcification has ceased the width of the fluorescent band varies not only with the rate of growth process but also with the dose of tetracyclines and the method by which it is given Intraperitoneal injection gives the widest band since elimination of the tetracyclines from the blood occurs much slower In addition the width of the fluorescent band is affected also by the duration of the administration and probably also by the type of tetracycline used since different tetracyclines are eliminated at a different rate from the blood (Kunin et al 1959 Kunin and Finland 1961 Owen 1965)

The literature contains no information on the causes of the varying width of the fluorescent band in the endochondral calcification process but it has been shown that the fluorescent band occurring in association with lamellar bone formation is influenced by the rate of growth as well as the duration of the administration of the fluorescent substance (Frost et al 1960 a and b 1961 a Lee 1963 1964 Landeros and Frost 1964) while the dose and mode of administration are not described as influencing the width of the fluorescent band (Frost et al 1960 a and b 1961 a) which may be explained by the fact that these variations are small and therefore difficult to record

The intensity of the fluorescence in the brightest ... fluores-cent band depends on the dose of OTC because a ... results ... a higher concentration of the OTC in the blood ... ll do (Kunin et al 1959 Buyske et al 1960 Kunin and ... Na... mann 1962 Owen 1965) and thereby larger deposi... here (Buyske et al 1960 Frost et al 1960 a Harris 1... et al 1962) The metaphyseal front of the fl... ent b... ut lined after intravenous injection than ... perit... of the same dose because the blood con... each ... value quicker after intravenous inje... caus... higher than after intraperitoneal injec... t al

1955 Buyske et al 1960 Knothe and Mahler 1960) Compared with these two methods of injection an oral dose results in a much lower blood concentration (Buyske et al 1960 Kelly and Buyske 1960 Knothe and Mahler 1960)

The intensity also increases with age which is difficult to explain with certainty This may argue for the assumption that the affinity in the zone of cartilage undergoing calcification increases or that the same dose produces a higher concentration in the blood in older experimental animals than in younger ones

The intensity is said to vary with the type of tetracycline The most effective fluorophore is said to be DCTC followed by CTC TC and OTC in the order given (Harris 1960 a Frost et al 1961 a Hattner and Frost 1962 Harris et al 1962 Owen 1963 Johnson 1964) On injection of corresponding doses the varying affinity of the Ca ions to the different tetracyclines must also be considered (Owen 1961 1963 1965 Kienitz 1965) as well as the varying concentration of tetracyclines in the blood after the same dose (Kunin et al 1959 Kunin and Finland 1961 Kienitz 1965)

In the present investigation it was observed that the colour of the fluorescent band varies with the concentration of OTC from golden yellow when the concentration is high to green yellow when it is low The colour of fluorescence thus varies considerably with the concentration of fluorophore with the result that the colour is not specific of the tetracyclines (Frost et al 1961 a) which was formerly believed to be the case (Harris 1960 a Harris et al 1962 Owen 1963 1965) This above mentioned specificity holds only for the same concentration of fluorophore in the fluorescent band

As previously mentioned the intensity of the fluorescence decreases with decreasing dose and at the same time the colour becomes more green yellow which is probably due to the disturbing blue or blue white autofluorescence in the area of deposition With further decrease of the dose it becomes more difficult to demonstrate the deposition The intensity of the fluorescence also depends on the exposure time because of photodecomposition of the fluorophore (Udenfriend 1962) In previous investigations (Milch et al 1957 1958 Boiko 1959) it has been reported that the deposition after intraperitoneal doses of down to 0 25 mg per kg bodyweight can be demonstrated by fluorescence microscopy It is very probable that the deposition after smaller doses given intravenously can be demonstrated Moreover in the present investigation a deposition was observed after an intravenous dose of 0 5 mg OTC

because of the difference in position of the calcification zone in relation to the line of erosion

The fluorescent band becomes fainter to a certain extent with time which is due to the resorption processes in the metaphysis. It was observed that the fluorescent band comes into contact with the bone marrow cavity after 3—6 days in the different growth zones, which suggests that the distance between the growth plate and the bone marrow cavity is related to the rate of the endochondral growth process (Lacroix 1951, Sissons 1953).

After deposition of the tetracyclines in the zone of cartilage undergoing calcification has ceased, the width of the fluorescent band varies not only with the rate of growth process but also with the dose of tetracyclines and the method by which it is given. Intraperitoneal injection gives the widest band, since elimination of the tetracyclines from the blood occurs much slower. In addition, the width of the fluorescent band is affected also by the duration of the administration and probably also by the type of tetracycline used, since different tetracyclines are eliminated at a different rate from the blood (Kunin et al. 1959, Kunin and Finland 1961, Owen 1965).

The literature contains no information on the causes of the varying width of the fluorescent band in the endochondral calcification process, but it has been shown that the fluorescent band occurring in association with lamellar bone formation is influenced by the rate of growth as well as the duration of the administration of the fluorescent substance (Frost et al. 1960 a and b, 1961 a, Lee 1963, 1964, Landeros and Frost 1964), while the dose and mode of administration are not described as influencing the width of the fluorescent band (Frost et al. 1960 a and b, 1961 a), which may be explained by the fact that these variations are small and therefore difficult to record.

The intensity of the fluorescence in the brightest part of the fluorescent band depends on the dose of OTC, because a large dose results in a higher concentration of the OTC in the blood than the small dose (Kunin et al. 1959, Buyske et al. 1960, Kunin and Finland 1961, Naumann 1962, Owen 1965) and thereby larger deposition of fluorophore (Buyske et al. 1960, Frost et al. 1960 a, Harris 1960 a, Harris et al. 1962). The metaphyseal front of the fluorescent band is better outlined after intravenous injection than after intraperitoneal injection of the same dose, because the blood concentration reaches its maximum value quicker after intravenous injection and because this value is higher than after intraperitoneal injection (Boothe et al. 1953, Dowling

and after destruction of the metaphyseal vessels (Trueta 1958 Trueta and Amato 1960 Trueta 1963 Hansson and Wiberg 1963 Wiberg 1964) Bevelander et al (1959 a and b 1960 b) have previously observed a similar cartilaginous tongue after treatment with tetracyclines and reported that it is caused by the fact that the tetracyclines disturbed the endochondral calcification process

The *primary cause of the development of the cartilaginous tongue is* surely the disturbance of the endochondral calcification process by the tetracyclines *which in turn results in deformation of the cartilaginous* trabeculae in the fluorescent band The deformation prevents the metaphyseal vessels *from proceeding further in epiphyseal direction It is also* conceivable that the resorption process is disturbed by the fact that the *mineralisation of the cartilaginous matrix is incomplete but this* appeared less likely because the cartilaginous tongue develops only epiphyseally *to the most deformed parts of the fluorescent band*

Much suggests that the changes in the most intensely fluorescent part *of the band are primarily caused by the tetracyclines disturbing the* endochondral calcification process and the cartilage matrix in this area being hypomineralised *This assumption is supported by the previous* observation that the tetracycline containing area which develops in association *with lamellar bone formation (Harris 1960 c Harris et al* 1962) as well as with the formation of enamel and dentine (Bevelander et al *1961 Gron and Johannessen 1961 Bevelander 1964 Nylen et al* 1964 Lofgren et al 1965 Omnell et al 1966) can under certain circumstances *be hypomineralised Moreover Bevelander et al (1960 a)* observed corresponding hypomineralised tetracycline containing areas in the calcite shell of larval sand dollars which lived in water containing tetracyclines (Bevelander 1964) Similar hypomineralisation *has also been recorded in other testaceans after treatment with tetracyclines* and it has been shown that calcite crystals are smaller in *tetracycline containing areas (Bevelander and Goss 1962 Bevelander* 1963) In addition Saxen (1965 1966) found hypomineralisation and *growth retardation in tissue cultures of shaft bones in the presence of* tetracyclines in concentrations of 1—10 mcg per ml

Gron and Johannessen (1961) found that an intraperitoneal injection of 100 mg of OTC per kg bodyweight to young rats resulted in tetra*cycline containing hypomineralised bands* in the dentine while a dose of 10 mg produced no microradiographically demonstrable hypomine*ralisation Bevelander et al (1961) observed that* an intramuscular injection of 150 mg TC per kg bodyweight (Cohlan et al 1963) to

weanling rats resulted in hypomineralised bands in both the dentine and the enamel (Bevelander 1964). On examination of deposition of different types of tetracyclines in lamellar bone formation in dogs it has been observed (Harris 1960 a, Harris et al. 1962) that microradiographically demonstrable hypomineralised bands occur after intravenous injection of various tetracyclines in doses of more than about 60 mg per kg bodyweight, while only CTC results in hypomineralised bands when given in doses of 33 mg per kg bodyweight.

Cohlan et al. (1962, 1963) claim that the growth in length of the fibula is reduced by on the average 40 % in prematures after a daily oral dose of 4×25 mg TC per bodyweight for 9—12 days, and that the retardation is less after 4×7 mg TC. They also state that the growth during the following period is somewhat higher than normal (Bevelander 1964). They used, however, a roentgenological method for determining the rate of growth which means that they registered the growth in length of the diaphysis, since at this age there are no bony epiphyses in the fibula. This suggests that during treatment with tetracyclines they measured retardation of the endochondral and perichondral calcification and during the period after treatment recorded the temporarily increased rate of the calcification process. In a similar investigation Chu et al. (1964) on the other hand could not show any definite disturbance of the growth process, which according to Chu et al. could be explained by the fact that OTC is a weaker chelating agent than the other tetracyclines. The prematures were in this case given 2×7.5 mg OTC daily per kg bodyweight intramuscularly for 10 days.

Owen (1963) claims to have demonstrated that therapeutic oral doses of different tetracyclines for a long period do not disturb the growth in length of the shaft bones, while large doses of CTC retard growth, but that growth becomes normal on withdrawal of treatment.

Moreover, Bevelander et al. (1959 a and b, 1960 b) like Smith and Chapman (1963) showed that the injection of 0.1—0.5 mg TC into the yolk sac of an egg does not affect the growth of chick embryos, in contrast to doses of 2.5—5.0 mg TC, which retard growth, inhibit mineralisation and result in partial deformation of the skeleton (Bevelander 1964, Johnson 1964). This type of injection results in a much higher blood concentration for a long time since the tetracycline is not lost, which enables deposition of larger amounts of the injected tetracyclines than in mammals, which bind at most 10 % of the dose injected (Buyske et al. 1960, Kelly and Buyske 1960, Urist and Ibsen 1963).

Summarising the toxic effect of tetracyclines on the calcification process has in the previous investigations only been demonstrated after parenteral doses of more than about 30 mg per kg bodyweight except when the tetracyclines were given in such a way that the blood concentration was high for a long time

In the present investigation no deformations were observed after intravenous injection of 0.5 mg OTC per kg bodyweight Only in one case a slight deformation was observed after administration of 1.0 mg OTC while deformities were common after doses of 10 and 25 mg OTC It is therefore probable that the critical level for development of deformities caused by the toxic effect of OTC on the endochondral calcification process is about 1.0 mg OTC per kg bodyweight under the above mentioned conditions

This does not exclude the possibility that OTC can have a slight toxic effect on the endochondral calcification process when given in doses below 1.0 mg OTC because hypomineralisation is a primary effect while deformation of the tetracycline containing cartilaginous trabeculae is a secondary effect However it appears hardly likely that doses of 1.0 mg OTC and less have any retarding effect on the rate of the growth process with certainty because these intravenous doses result in low and transient blood concentration (Dowling 1955 Musselman 1956 Naumann 1962)

In previous investigations (Bevelander et al 1959 a 1960 b Cohlan et al 1962 1963 Owen 1963 1965) Smith and Chapman 1963 Bevelander 1964) it has been shown that large doses of tetracyclines retard the proliferation and hypertrophy of the cartilage cells This results in reduction of the rate of growth of the shaft bone On the other hand no such retardation could be demonstrated after small doses given for a corresponding period (Bevelander et al 1959 a 1960 b Cohlan et al 1962 1963 Rolle et al 1962 Owen 1963 1965 Chu et al 1964) In addition Taguchi (1963) has shown that a concentration of tetracycline less than 10 mcg per ml does not affect the growth of cartilage and bone cells in tissue culture while a concentration of 50 mcg per ml does

It therefore appears that intravenous doses of 0.5 and 1.0 mg OTC per kg bodyweight do not with certainty affect the proliferation and hypertrophy of cartilage cells but such an effect cannot be excluded after intravenous doses of 10 and 25 mg OTC per kg bodyweight since the blood concentration after these doses achieves a high maximum and the tetracyclines persist in the blood stream for several hours (Hunt

weanling rats resulted in hypomineralised bands in both the dentine and the enamel (Bevelander 1964). On examination of deposition of different types of tetracyclines in lamellar bone formation in dogs it has been observed (Harris 1960 a, Harris et al. 1962) that microradiographically demonstrable hypomineralised bands occur after intravenous injection of various tetracyclines in doses of more than about 60 mg per kg bodyweight, while only CTC results in hypomineralised bands when given in doses of 33 mg per kg bodyweight.

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Owen (1963) claims to have demonstrated that therapeutic oral doses of different tetracyclines for a long period do not disturb the growth in length of the shaft bones, while large doses of CTC retard growth but that growth becomes normal on withdrawal of treatment.

Moreover Bevelander et al. (1959 a and b, 1960 b), like Smith and Chapman (1963), showed that the injection of 0.1—0.5 mg TC into the yolk sac of an egg does not affect the growth of chick embryos in contrast to doses of 2.5—5.0 mg TC, which retard growth, inhibit mineralisation and result in partial deformation of the skeleton (Bevelander 1964, Johnson 1964). This type of injection results in a much higher blood concentration for a long time since the tetracycline is not lost, which enables deposition of larger amounts of the injected tetracyclines than in mammals, which bind at most 10 % of the dose injected (Buyske et al. 1960, Kelly and Buyske 1960, Urist and Ibsen 1963).

plate are continually migrating in epiphyseal direction at rates which vary with the region of growth and with the age of the experimental animals The width of the fluorescent band after intravenous injection was found to vary with the amount of OTC and the rate of growth in the region The intensity varied with the amount of OTC and with the age of the animals

Amounts of bound OTC are released the first period after the time of injection because OTC containing cartilage and bone tissue is entirely or partly resorbed

Intravenous injections of doses of more than 1 0 mg OTC per kg bodyweight often produced more or less deformed cartilaginous trabeculae in and epiphyseally to the fluorescent band These pathological changes increased in frequency extension and severity with increasing dose of OTC and with the rate of growth and were probably affected also by the degree of loading of the growth zone The primary cause was probably that the OTC had a toxic effect on the endochondral calcification process which gives rise to a hypomineralised fluorescent band which is readily deformed It cannot be excluded that a certain hypomineralisation occurs after parenteral doses of 0 5 and 1 0 mg OTC per kg bodyweight but such small doses are presumably not enough to reduce the rate of the growth process

2 DETERMINATION OF RATE OF GROWTH FROM THE GROWTH PLATE

The fluorescent OTC is bound as previously mentioned to the areas in the growth region of the diaphysis which are undergoing endochondral calcification at the time of the injection The site of the calcification process can therefore be marked at different times by repeated injections each producing a fluorescent band which can be used for determining the rate of endochondral growth since the line of erosion and the endochondral calcification process accompany one another

It appears best to use the metaphyseal front of the fluorescent band for this determination because this front marks the border between the zone of completely calcified cartilage and the zone of cartilage undergoing calcification at the time of the injection The growth in length from the growth plate during the interval between 2 injections thus corresponds to the distance between the metaphyseal fronts of the fluorescent bands

It appears advisable to give intravenous injections of 1 0 mg OTC

per kg bodyweight since the marking then occurs rapidly and is distinct at the same time as OTC in this dose has no definite retarding effect on the rate of the growth process

It is possible to determine the growth in length for such short intervals as a few hours as well as for periods of several days. In the following investigation of the growth in length it was decided to determine the growth per day since any diurnal variation of the rate of growth in this way will not affect the result. The interval between the last injection of OTC and the sacrifice of the animal was 10 minutes since this short period is sufficient to give exact marking.

In the following part of the investigation the mean error of the determination of growth in length per day from different growth plates was determined because it is necessary to assess the reliability of the method.

a. Material

In the investigation of the error of the method 3 rabbits were used which were 35 days old at the end of the experimental period. These animals were given 1.0 mg OTC per kg bodyweight intravenously on 2 occasions at an interval of 24 hours. The animals were killed 10 minutes after the last injection in the usual way.

The following growth regions were used for determination of the error of the method: proximal tibia (fibular part), proximal and distal fibula from both halves of the body.

b. Method

Longitudinal sections of the shaft bone were prepared and the fluorescent microscopic examinations were carried out in the way previously described (see page 12).

The growth from the growth plates was determined by measuring the distance along the metaphyseal trabeculae in the direction of the shaft bone between the metaphyseal fronts of the two fluorescent bands (Fig. 12). The measurement was done only in the region of the metaphysis where the metaphyseal trabeculae meet the growth plate almost at right angles. This measuring area was therefore well defined in all of the regions studied. The measurements were made on sections where the metaphyseal trabeculae could be traced for hundreds of microns in metaphyseal direction from the line of erosion. The distance between the metaphyseal fronts of the fluorescent bands was deter-

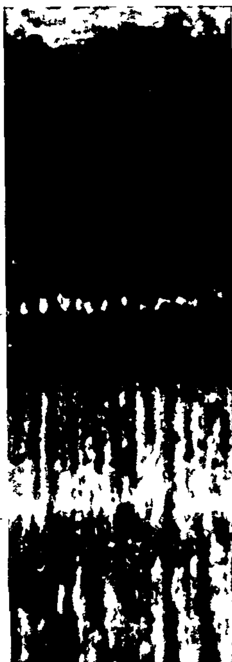


Fig. 12. Localisation of OTC in association with endochondral calcification after intravenous injections of 1.0 mg per kg bodyweight at 59 days (lower fluorescent band) and at 60 days of age (upper fluorescent band). Animal was killed 10 minutes after last injection. Distance between metaphyseal fronts of the two fluorescent bands indicates longitudinal growth during 60th day. Section from proximal fibula (120×).

mined in 2 parts of the above mentioned area in each section and in 5 sections which thus gave a total of 10 measurements for each growth region.

per kg bodyweight since the marking then occurs rapidly and is distinct at the same time as OTC in this dose has no definite retarding effect on the rate of the growth process

It is possible to determine the growth in length for such short intervals as a few hours as well as for periods of several days In the following investigation of the growth in length it was decided to determine the growth per day since any diurnal variation of the rate of growth in this way will not affect the result The interval between the last injection of OTC and the sacrifice of the animal was 10 minutes since this short period is sufficient to give exact marking

In the following part of the investigation the mean error of the determination of growth in length per day from different growth plates was determined because it is necessary to assess the reliability of the method

a *Material*

In the investigation of the error of the method 3 rabbits were used which were 35 days old at the end of the experimental period These animals were given 1 0 mg OTC per kg bodyweight intravenously on 2 occasions at an interval of 24 hours The animals were killed 10 minutes after the last injection in the usual way

The following growth regions were used for determination of the error of the method proximal tibia (fibular part) proximal and distal fibula from both halves of the body

b *Method*

Longitudinal sections of the shaft bone were prepared and the fluorescent microscopic examinations were carried out in the way previously described (see page 42)

The growth from the growth plates was determined by measuring the distance along the metaphyseal trabeculae in the direction of the shaft *bone between the metaphyseal fronts of the two fluorescent bands* (Fig 12) The measurement was done only in the region of the metaphysis where the metaphyseal trabeculae meet the growth plate almost at right angles This measuring area was therefore well defined in all of the regions studied The measurements were made on sections where the metaphyseal trabeculae could be traced for hundreds of microns in metaphyseal direction from the line of erosion The distance between *the metaphyseal fronts of the fluorescent bands* was deter

mal (Table 3) and distal fibula (Table 4) were 17.4 μ and 15.2 μ respectively corresponding to 3.8 % and 3.4 % of the average rate of growth per day from the growth plates in these growth regions.

The measuring error, i.e. the difference observed in the determination of the growth at different times, constituted a considerable part of the total mean error and varied between 6.8 μ and 8.0 μ for the different growth regions. The other part of the total mean error was due to the use of sections from different growth regions and was reflected partly as a difference between sections from the same growth region and partly as a difference between the right and left sides. On the other hand no difference was found with certainty between the different parts of the area measured in the section.

The values given above apply to the error of the method for a single determination. In the following examinations the mean value of 10 different determinations in a growth region was used with the result that the mean error and its various components was reduced.

Under these conditions the mean error of the determination of the rate of growth from the proximal growth plate of the tibia was 4.2 μ (0.8 %) while the corresponding values for the proximal and distal growth plates of the fibula were 5.5 μ (1.2 %) and 4.8 μ (1.1 %) respectively.

d. *Discussion*

It is thus possible to determine the rate of growth per day from different growth plates by repeated marking of the endochondral calcification process with the aid of the tetracyclines. This possibility has previously been suggested by Hulth and Olerud (1962) while Frost et al. 1960 a and b) claimed that the tetracyclines are deposited only transiently during the endochondral calcification process and therefore cannot be used for determining the growth from the growth plate.

In previous investigations of lamellar bone the rate of growth has been determined from a single fluorescent band or with the aid of multiple fluorescent bands.

In the former case the width of the fluorescent band was determined after which the rate of growth was calculated from the period of administration (Frost 1960 b, Landeros and Frost 1964) but the width of the calcification zone was not taken into consideration and since the deposition of the tetracyclines continues as long as the tetracyclines are

in the circulation determinations by this method do not give correct values

In the last mentioned case where the determination was made from multiple fluorescent bands the growth was determined in different ways. Use was often made of the distance between the fluorescent bands or in other words the width of the intermediate autofluorescent area (Harris 1960a Landeros and Frost 1964 Sissons and Lee 1964 Lee 1965). This method has inherent sources of error because the two measuring points adjacent to the fluorescent bands do not correspond to one another. The measuring point at the band that appears first corresponds to the border between the calcification zone and the osteoid containing no calcium at the time when the demonstrable deposition after the first dose of tetracycline ceases while the measuring point adjacent to the other fluorescent band corresponds to the border between the calcification zone and the completely calcified area when the second tetracycline dose is deposited. Lee (1963 1964) like Tapp (1966) measured instead the distance between the midpoints or the most intense parts of the fluorescent bands but even then various factors can affect the results since such a calculation assumes that the fluorescent bands correspond exactly to one another.

It is more correct to measure the distance between those parts of the fluorescent bands which mark the border between the entirely calcified area and the zone of cartilage undergoing calcification at the moment the deposition of tetracycline begins. In the endochondral calcification process this border corresponds to the metaphyseal fronts of the fluorescent bands. The distance between identical points is measured regardless of the dose of tetracycline, the type of tetracycline and the interval between the last administration and the removal of the preparation. It is essential however that the doses of tetracycline should be given in the same way.

The total error of the method in the determination of the growth from multiple fluorescent bands comprises several components which are related to the sections and to the reading in the fluorescence microscope.

The difference observed in the determination of the growth at different times consists entirely of a measuring error with certainty and is not a sign that the sections have changed with time.

No difference was found between the measurements in the different

parts of the area measured which means that it is immaterial which part is measured in the study of growth

On comparison between sections from the same growth region a definite difference was observed in the proximal tibia and distal fibula but no definite difference was found between sections from the right and left sides In the proximal fibula on the other hand there was a difference between the two sides The cause of this difference between sections from the same growth region and between sections from the right and left growth regions is surely due to the fact that the direction of the sections can vary within certain limits without this variation being observed with certainty in the microscope or that sections are taken from varying parts in the central area of the growth region

On the other hand it is not likely that the different steps in the preparation of sections are involved in these sources of error because the rate of growth is determined in mineralised parts of the growth region

The two components of the total error of the method appear to be of largely equal magnitude and to vary but slightly from one growth region to another

The reason why the mean error for the proximal fibula is somewhat larger than that for the proximal tibia is that the former growth region is relatively small and that its growth plate runs a somewhat varying course This implies that sectioning is more difficult and the measuring area smaller This is also reflected in the comparison between the distal fibula and the proximal tibia

The total error of the method in the determination of growth was calculated as about 1 5 μ against 5 μ for 10 determinations with a slight variation of the different growth regions The reason why the percentage was relatively higher for the proximal fibula than for the proximal tibia was that the rate of growth is higher in the proximal tibia than in the proximal fibula This also applies to comparisons between the proximal tibia and the distal fibula

It was thus found that the error of the method is influenced only slightly by the choice of region of growth studied This means that the error of the method is about the same in different growth regions where the growth plate is practically at right angle to the longitudinal axis of the long bone and the central trabeculae These conditions are also present in the distal ulna proximal and distal radius as well as the distal tibia

e. Summary

The sources of error occurring in the determination of the rate of growth from the growth plate with the aid of multiple marking of the endochondral calcification process with OTC were analysed.

The experimental animals were given 1.0 mg OTC per kg bodyweight intravenously on 2 occasions at an interval of 24 hours and the animals were killed 10 minutes after the last injection. The growth regions of long bones were treated and examined in the way described previously.

The growth in length from the growth plate during the interval between the injections, i.e. the distance between the metaphyseal fronts of the fluorescent bands in the longitudinal direction of the long bone was determined in well defined parts of the metaphyseal area.

The error of a single determination of growth from the growth plate was calculated as about 15 μ with slight variation from one growth region to another. This error of the method corresponded to 2.5 % of the growth per day in the proximal tibia, 3.8 % of the growth per day in the proximal fibula. This variation was due largely to the rate of growth being higher from the proximal growth plate of the tibia than from the proximal growth plate of the fibula.

The error of the method was due to an equal extent to the preparation of the sections and to the reading of the results in the fluorescence microscope.

Multiple marking of the endochondral calcification process with OTC thus allows a rapid, simple and at the same time exact determination of the growth from the growth plate for short periods without any toxic effect on the growth rate with certainty.

CHAPTER III

RATE OF GROWTH FROM THE GROWTH PLATE AND ITS RELATION TO THE MORPHOLOGY OF THE GROWTH PLATE IN NORMAL RABBITS

A Survey of Literature

The first publication dealing with the rate of growth of a long bone from its end regions appears to be that published by Stephen Hales (1731, 1748). He studied the rate of growth of a long bone, probably a tarso-metatarsal bone (Lacroix 1951) or tibia (Payton 1932, Bisgard and Bisgard 1935) in chicks and found that the growth occurred mainly from its proximal end region. Similar experiments on the tibia of different animals were carried out some years later by Duhamel (1743b) who observed that the growth in this long bone occurred mainly from its proximal end region. These publications were later followed by a large number of investigations. Some of which were carried out only on the diaphysis and some also included other parts of the end regions of the long bone. This section will be concerned with the growth in length of the diaphysis. It should, however, be pointed out that the difference between the total growth in length of the long bone and the rate of growth in length of the diaphysis is as a rule small.

From investigations on the rate of growth of different long bones it is known that the length of the long bones increases along an S-shaped curve during the prenatal and postnatal period of growth and this also holds for the growth in length of the different diaphyses. This means that the rate of growth during foetal life is first very slow and later increases to reach a maximum presumably during the middle and latter part of the foetal period after which it rapidly decreases before birth (Schulz 1960, Israelsohn 1960, Sissons 1961).

According to Israelsohn (1960) birth has only a slight influence on the growth curve. The rate of growth after birth shows the same evenly decreasing tendency as before and appears to be the same for both sexes. This postnatal period in man is said to comprise the first 3—5 years of life (Maresh and Deming 1939, Green and Anderson 1947,

Goff 1960 Anderson et al 1963 Taillard and Morscher 1965) Bergmann (1931) on the other hand claimed that there is a period of increased rate of growth starting at the age of 1 year and lasting for some years Later the rate of growth again decreases

The period of decreasing rate of growth is followed by a period of constant rate of growth which in man comprises the ages of 6—9 years After the rate of growth has become fairly steady it again begins to increase slowly and reaches its maximum between the ages of 10—12 years in females and between 12—14 years in males (Green and Anderson 1947 Anderson et al 1963) Tupman (1962) who studied the rate of growth of the femur tibia and vertebrae in man at a skeletal age of 7—17 years could not demonstrate any period with increased rate of growth and found that the rate of growth is constant until the skeletal age of about 12 years in girls and about 14 years in boys On the other hand he did observe a growth spurt for the vertebrae immediately before the skeletal age of 12 and 14 years in girls and boys respectively which results in a corresponding growth spurt for the total length of the body during this period

During the following age period until the end of the period of growth the rate of growth decreases rapidly In man this period consists of about 4 years for both sexes which means that the growth ceases first in girls (Green and Anderson 1947 Tupman 1962 Anderson et al 1963)

The rate of diaphyseal growth is not the same for all bones but differs from one bone to another (Gill and Abbott 1942 Schmid and Kunle 1958 Heikel 1960 Ryöppy 1965 Taillard and Morscher 1965) According to Gill and Abbott (1942) the rate of growth of the tibia is faster than that of the femur during the first part of the postnatal period while the rate of growth during the latter part is higher for the femur than for the tibia which ceases to grow somewhat earlier than the femur It is also claimed that the rate of growth of the tibia is more even than for the femur (Gill and Abbott 1942)

The variation of the rate of growth with age has not been studied so extensively in various experimental animals as in man and as a rule for only short periods of postnatal growth period and usually during the latter part The results of these investigations (Ray et al 1950 Bhaskar et al 1950 Heikel 1960 Wray and Goodman 1961) agree well with the results of the above mentioned investigations in man

The growth from the different growth plates like that from the end regions also follows an S shaped curve The rate of growth from the different growth plates has not been given for the prenatal period

even though this period has been investigated by Bisgard and Bisgard (1935) and Gill and Abbott (1942). Several investigations of the rate of growth after birth have shown that it decreases with age (Payton 1932, Bisgard and Bisgard 1935, Aries 1941, Gill and Abbott 1942, Sissons 1953, Heikel 1960, Tapp 1966). Bisgard and Bisgard (1935) claimed that this decrease does not begin until the latter part of the postnatal growth period and that the rate of growth during the first part of the postnatal period is constant. Payton (1932) on the other hand believed that the rate of growth decreases with age during the major part of the postnatal growth period and that this decrease becomes more and more marked towards the end of the growth period. This decrease of the rate of growth is different for different growth plates. It is greatest for the most slowly growing growth plates, while the opposite holds for the growth plates with the highest rate of growth (Payton 1932, Bisgard and Bisgard 1935, Gill and Abbott 1942).

This means that the ratio between the growth from the proximal and distal growth plates of a long bone varies with age (Payton 1932, Brash 1934, Gill and Abbott 1942) as it does for the end regions of the long bone (Ollier 1867, Brodin 1955, Llo 1960). In a large number of investigations it has, however, been assumed that this ratio is constant throughout the growth period (Digby 1916, Bergmann 1929, 1931, Phemister 1933, 1935, Wilson and Thompson 1939, Blomqvist and Rudström 1943, Green and Anderson 1947, Heikel 1960, Salter and Harris 1963, Anderson et al. 1963, Guldhammer 1963, Nordentoft 1964, Ryoppy 1965). In several of these investigations large variations have been observed which have, however, been explained by the error of the method and individual variations of the experimental material, while the age factor has for various reasons not been taken into consideration.

The distribution of the growth during the prenatal period appears to be more even than later but to vary between different long bones. This is supported by the observations by Bisgard and Bisgard (1935) and by Gill and Abbott (1942). The last two authors observed in a new born baby that the growth of the diaphysis of the tibia and of the femur was 50 and 46 % respectively from the proximal growth plate. Since they determined the rate of growth roentgenologically with the aid of transverse lines which appeared in the child because the mother had during the last months of pregnancy been treated with bismuth, their findings hold for the last 5 months of intrauterine life. Bisgard and Bisgard (1935) obtained similar results, namely 49 and 38 % for

The growth plate is equally developed in both sexes during the earliest part of the growth period. It is above all the thickness of the zone of germinative cells that is striking, but also the other zones are thicker than in older individuals (Harris et al. 1965, Morscher et al. 1965). During the earliest part of sexual maturation a sex difference begins to appear and then the growth plate becomes broader in males than in females (Morscher et al. 1965). Towards the end of the growth period the growth plate is broader in males than in females and disappears later in association with fusion between the bone epiphysis and diaphysis (Bargmann 1964, Bucher 1965).

The thickness and morphology of the growth plate varies considerably between different kinds of animals, which is due to some extent to differences in rate of growth (Harris 1933, Sissons 1953).

In one and the same individual the thickness and morphology of the growth plate varies with its site. According to several authors there is a proportional relationship between, on the one hand, rate of growth and on the other, the thickness of the growth plate (Fahmy 1964, Taillard and Morscher 1965), the height of the different zones (Harris 1933, Llo 1960) as well as the number of cells in the cell column (Harris 1933) and in the different zones (Harris 1933, Trueta and Morgan 1960). Johnson (1964) found that the relationship between the morphology and rate of growth of the growth plate varies with age because the cartilage cells develop slower in older individuals than in younger ones. In addition it has been observed that the distal growth plate of the fibula is thicker than its proximal plate even though its rate of growth is slower (Ollier 1867).

B. Author's Investigations

It is clear from the survey of the literature that opinions differ concerning the normal growth process. This applies above all to the rate of growth and its relation to the morphology of the growth plate. The reason appears to be that, with but few exceptions, the methods used formerly for determining the rate of growth did not allow correlation between the rate of growth and morphology.

Therefore the rate of growth and its relation to the morphology of the growth plate were examined in the rabbit under normal conditions. The examination was concentrated on the age period between 20—70

days since the experimental investigations published were as a rule made during this period of life. The growth process was studied in regions which are readily accessible to operations and whose growth plates are oriented at right angles to the longitudinal axis of the bone. Factors which might influence the normal rate of growth, such as sex, litters and nutrition were studied.

Since the investigation was concerned with the morphology of the growth plate it was decided to study the length of the cell columns. In the rabbit the growth plates contain numerous cell columns of which a large number extend from the border between the zone of germinative cells and the zone of proliferative cells through the following zones to the line of erosion (Fig. 2, 3). The length of these complete cell columns is thus an excellent measure of the active zones and of the capacity of the growth apparatus (Kember 1960, Trueta and Morgan 1960, Rigal 1962). It should be added that the zone of germinative cells which varies considerably in thickness in a growth plate probably does not take any appreciable part in the activity of the growth apparatus compared with that of other zones (Kember 1960, Rigal 1962).

The length of the complete cell column is a better measure of the growth apparatus than the number of cells in the cell column and the number of cells in different zones of the cell column. One of the reasons is that the division of the cells in a cell column occurs almost simultaneously but at various times in different cell columns. This means that the number of cells in the cell column varies considerably and that the borders between the stages of development in different columns vary, as pointed out by Trueta and Little (1960) and Rigal (1962). Another reason is that it appears to be difficult to determine with certainty the number of cells in the cell column because the cells in the cell column may be divided among several sections in the histological examination.

1. MATERIAL

The rate of growth and its relation to the growth plate was determined in all together 35 rabbits from 9 litters with 3—6 animals in each litter (see page 41). The growth was determined for the 20th, 30th, 40th, 50th, 60th and 70th day of life in 5, 10, 5, 5, 5 and 5 animals respectively. The members of the litter were distributed over the experimental period in order to obtain as equal a distribution as

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It is clear from the survey of the literature that opinions differ concerning the normal growth process. This applies above all to the rate of growth and its relation to the morphology of the growth plate. The reason appears to be that, with but few exceptions, the methods used formerly for determining the rate of growth did not allow correlation between the rate of growth and morphology.

Therefore the rate of growth and its relation to the morphology of the growth plate were examined in the rabbit under normal conditions. The examination was concentrated on the age period between 20—70

of 7 % sodium formate and 40 % formic acid for 20—30 days. Paraffin sections about 10 μ thick were prepared with the help of a slide microtome. In the proximal growth region of the tibia frontal sections were placed in the middle of the growth plate and the plane of section was parallel to the longitudinal direction of the cell columns which was checked in the microscope during sectioning. This also holds for sectioning of the distal growth plate of the tibia. In the two end regions of the radius sections were cut from the central part of the growth plates parallel to the cell columns. The plane of the sections was placed at right angle to the ulnar surface of the radius.

Paraffin sections obtained from the above mentioned regions were stretched on water (Clayden 1962) at a temperature of at most 35°C and then allowed to dry in the air at room temperature for 1 day. The sections were stained in haematoxylin eosin according to Ehrlich and were mounted in DePeX (Gurr, London).

For the light microscopic examination use was made of the same type of microscope as that previously described with the same objective and ocular equipment.

For determining the length of the cell columns that area of the growth plate was chosen where the cell columns are practically perpendicular to the erosion line. The length of the cell columns was determined only in columns which were continuous from the border between the zone of germinative cells and the zone of proliferative cells right to the erosion line. In the above mentioned area 4 cell columns were selected from each section which satisfied the conditions given and this determination was made in 5 sections from each growth plate, so the length of 20 cell columns was determined in each growth plate.

3. RESULTS

a. *Rate of Growth from Different Growth Plates*

The rate of growth from the growth plates (Table 5) examined followed during the selected age period of 20—70 days definite curves which appeared to be characteristic of the different growth plates.

PROXIMAL TIBIA

The rate of growth per day from the growth plate of the proximal tibia (Fig. 13) showed a very regular curve. During the actual age

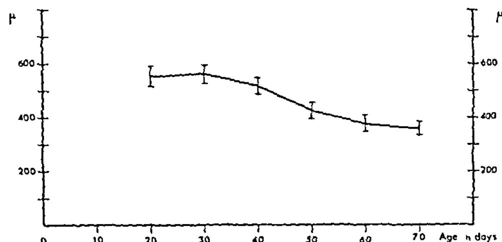


Fig 13 Rate of growth per day from proximal growth plate of tibia (Table 5)

period the rate of growth was highest in the beginning of this period when it was 561 ± 30 μ per day at 30 days of age which was slightly more than the growth rate at 20 days of age when it was 504 ± 36 μ per day During the following period the rate of growth gradually fell to 362 ± 26 μ per day at 70 days of age

DISTAL TIBIA

Also in this growth area the growth rate changed in a corresponding manner Its highest value appeared to be reached at about 30 days of age with 489 ± 43 μ per day while the corresponding at 20 days of age was 480 ± 41 μ per day The rate of growth then appeared to have reached its maximum and gradually decreased to 234 ± 27 μ per day at 70 days of age

PROXIMAL FIBULA

The rate of growth from the growth plate of the proximal fibula was highest at 30 days of age when it was 479 ± 34 μ per day while the corresponding value for 20 days of age was 448 ± 37 μ per day After 30 days of age the rate of growth slowed down and was at 70 days of age 332 ± 22 μ per day

DISTAL FIBULA

The rate of growth from the distal growth plate of the fibula was the same as that of the adjacent distal tibia throughout the investigation period

days after birth

30—

20—

A

days after birth

—40

—60

B

Fig 14 Growth from distal growth plate of radius during 30th (A) and 0th (B) *day after birth (80×)*

PROXIMAL RADIUS

The rate of growth in the proximal radius was much lower than in *other regions studied It was highest at 20 days when it was 170±32 μ*

per day During the following age period the rate fell slowly with the result that at 70 days it was only 30 ± 16 μ per day

DISTAL RADIUS

The rate of growth from the distal growth plate was much higher than from the proximal growth plate The highest rate was noted at 30 days (Fig. 14 A) when it was 486 ± 30 μ per day against 444 ± 40 and 470 ± 39 μ per day at 20 and 40 days respectively During the following period the rate fell to 352 ± 19 μ per day at 70 days (Fig. 14 B)

COMPARISON BETWEEN DIFFERENT GROWTH PLATES AND DIAPHYSES

Comparison of the rate of growth from different growth plates showed that it was highest in the proximal tibia during the age period studied and lowest in the proximal radius The rate of growth in the other regions studied throughout the experimental period lay between the above mentioned regions At 20 days the rate of growth in the distal tibio fibula was higher than in the proximal fibula and distal radius At 30 days the above mentioned regions were at about the same level During the rest of the age period the rate of growth in the distal radius was higher than in the other regions but lower than that of the proximal tibia The rate of growth from the growth plates of the proximal fibula and distal tibio fibula was practically the same until about 40 days of age after which the rate of growth for the proximal fibula began to be higher than that of the distal tibio fibula and to approach the rate of growth for the distal radius and the proximal tibia

The rate of growth of the various diaphyses showed the same tendency as that from the different growth plates The rate of growth of all the diaphyses was highest in the beginning of the growth period and particularly at 30 days after which it decreased but at different rates for different diaphyses During the entire age period the rate of growth of the diaphysis of the tibia was highest while that of the fibula was somewhat lower and that of the radius lowest

PERCENTAGE OF GROWTH IN LENGTH OF THE DIAPHYSIS FROM ITS PROXIMAL AND DISTAL GROWTH PLATES

The relative growth from the different growth plates varied with age in a regular manner (Table 5 and Fig. 15)

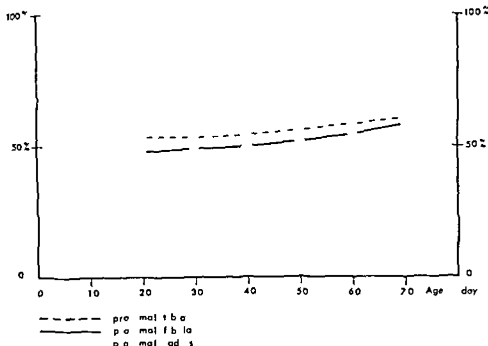


Fig 15 Rate of growth per day from proximal growth plate of tibia fibula and radius in per cent of rate of growth per day of diaphysis (Table 5)

Examination of the growth of the tibial diaphysis showed that in the beginning of the experimental period the growth from the proximal growth plate was 53 6 ± 0 7 % This percentage increased so that at 50 days it was 56 1 ± 0 7 % and finally at 70 days 60 8 ± 1 9 %

The same pattern was observed for the growth of the fibular diaphysis though it was initially different At 20 days the value for the proximal fibula was 48 0 ± 0 8 % and increased gradually and at 30 days it was 49 5 ± 0 7 % at 50 days 52 3 ± 0 7 % and finally at 70 days it was 58 7 ± 1 0 % The rate of growth during the first part of the age period was thus higher distally than proximally while the relationship changed between 30 and 40 days

The growth of the radial diaphysis during the entire growth period occurred mainly from the distal growth plate the proportion increasing with age The value for the proximal radius at 20 days was 27 6 ± 3 9 % but at 70 days it was 7 7 ± 3 5 %

b Length of Cartilage Cell Columns in Different Growth Plates

In all of the growth plates from animals aged 20—70 days there were numerous cell columns extending from the line of erosion to the border between the zone of germinative cells and the zone of proliferative cells These columns thus provided a measure of the height of the zones of proliferative hypertrophic and degenerative cells

ANALYSIS OF THE ERROR OF THE METHOD

In the examination of the error of the method the growth plate of the proximal tibia was selected The length of the cell columns in the preparations was examined twice at an interval of one month The data were studied statistically and the results are given in Table 6

The assumption was made that there is no difference between corresponding areas on the left and right sides The differences between the length of the cell columns found on statistical analysis were therefore most probably due to the error of measurement

The total error of the method was found to be 18 9 μ which corresponded to 2 8 % of the average length of the cell column in the growth plate of the proximal tibia The measuring error which is identical with the residual value proved to be the largest of the components of the error of the method In the present investigation it was 17 8 μ or 2 6 % of the average length of the cell column

The above mentioned error of the method was calculated for a single determination and was much smaller when the mean of 20 different cell columns was used Then the mean error was found to be 4 2 μ or 0 6 % of the average length of the cell column

The statistical analysis of the length of the cell columns revealed an irregular variation in that the cell columns in some experimental animals were longer in the left growth plate than in the right growth plate while the ratio was the reverse in other experimental animals Otherwise no certain interaction was found between the different causes of the variation

LENGTH OF CELL COLUMNS (TABLE 7)

Proximal Tibia

The curve for the length of the cell columns at different ages in the growth plate of the proximal tibia (Figs 16 17) resembled that for its

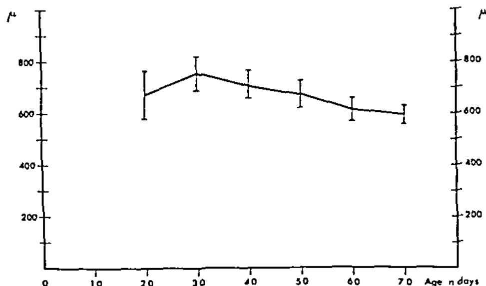


Fig 16 Length of cartilage cell columns in proximal growth plate of tibia (Table 4)

rate of growth The cell columns were longest at 30 days when they were 753 ± 66 μ while they appeared to be shorter at 20 days The length decreased relatively slowly with age and at 70 days it was 591 ± 35 μ

Distal Tibia

This growth plate was examined only at 30 50 and 70 days because it was much more difficult to obtain satisfactory sections from this region than from the other regions In this growth plate most of the cell columns are more or less curved and are almost straight in only a small area which must be used for the examination Here the same tendency was found as in the proximal growth plate The length of the cell column decreased from 621 ± 18 μ at 30 days to 460 ± 10 μ at 70 days

Proximal Radius

Compared with the other growth plates the cell columns in the growth plate of the proximal radius were short At the beginning of the investigated age period they were at most 242 ± 16 μ at 20 days They became shorter with age and at 70 days they were 171 ± 50 μ

foetal material than in embryonic material In previous investigations of the effect of shrinkage most investigators have used embryonic preparations In addition dehydration and embedment were done by a more gentle method in the present investigation

The remaining part of the histotechnical treatment probably resulted in no further shrinkage, as this was done carefully (Patten and Philpott 1921 Siiff 1950) It was observed in the preliminary investigations that the length of the cell columns was reduced considerably when the paraffin sections were exposed to temperatures above 40°—50°C and that the reduction was probably more pronounced when the sections were exposed to this temperature for several hours Such findings have also been reported previously by Tarkhan (1931) and Siiff (1950)

The sources of error which can be expected in the histotechnical treatment probably cause a reduction of a few per cent of the true length of the cell column and these sources of error are largely eliminated in comparison between different determinations Therefore it did not appear necessary to correct the measured length of the columns in the different growth plates because of these sources of error

It is apparent from the preceding sections that the histotechnical treatment probably did not cause the differences responsible for the error of the method because the histotechnical treatment probably affected all cell columns to the same extent

Statistical analysis showed an irregular interaction in that the cell columns in sections from the right growth region were longer than in sections from the left growth region in some of the animals while the relationship was the opposite in the other experimental animals This difference is probably not a sign of a normal variation because there was no corresponding variation of rate of growth and because the difference could very well be explained by the sources of error in association with the sectioning In preliminary investigations it was observed that the length of the cell columns in the growth plate of the proximal tibia varied with their position the further dorsally the longer they were Moreover in frontal sections the central cell columns were shorter than the peripheral ones This means a side difference in those cases where sections were not taken from identical parts of right and left growth regions or at the same angle On the other hand the statistical analysis showed no difference between sections from the same growth region with certainty which can probably be explained by the fact that different sections were taken at practically the same angle and that the last section was taken at most 200 μ dorsally to the first section

The error of the method is due largely to the determination of the length of the cell columns since the length of the cell columns probably varies to a certain extent

In this examination no certain difference was found between the determination of the length of the cell columns on different occasions which suggests that the sections did not change with time and that the measurement of the length of the cell columns did not vary from one time of measurement to another

The area used in the determination of the length of the cell columns in different growth plates studied probably varied only slightly because all were examined by the author On the other hand the source of error due to the sectioning surely varies to a certain extent from one growth region to another In the proximal and distal growth plates of the radius this source of error was probably equally large as in the growth region of the proximal tibia somewhat larger in the distal tibia since it is more difficult to obtain satisfactory sections from this growth region than from other growth regions examined

This investigation was concerned with normal growth in the rabbit during the first part of the postnatal growth period namely between 20 and 70 days This age period corresponds in man roughly to the period between 2 and 8 years Heikel (1960) having shown that 1 day in the rabbit corresponds to about 40 days in man

During this age period there is probably no difference between experimental animals of different sexes partly because no certain difference was found with sex in the examination of 30 day old animals and secondly because a sex difference was not noted until after 9 years of age in homo (Maresh and Deming 1939 Green and Anderson 1947 Goff 1960 Anderson et al 1963) which corresponds more than 80 days in the rabbit

The investigation produced evidence for the assumption that the highest rate of growth during the age period studied occurs during the first part but at different times in various growth regions The rate of growth from the growth plate in the distal radius and proximal fibula is thus higher at 30 days than at 20 days while the difference is only small in the proximal tibia and the distal tibio fibula The relation in the proximal radius is the opposite with a higher rate of growth at 20 days than at 30 days

It appears probable that the above mentioned differences in rate of growth between 20 and 30 days are due to the effect of local factors and

secondly to change in nutrition occurring during the age period between 20 and 30 days in the rabbit

The occurrence of a similar variation of the rate of growth in man has been observed by Bergmann (1931) and in the rat by Tapp (1966) while a corresponding variation could not be shown in other investigations (Maresh and Deming 1939 Green and Anderson 1947 Goff 1960 Anderson et al 1963 Tullard and Morscher 1965) This may be because the growth in previous investigations was recorded at long intervals with the result that transient changes in the rate of growth could not be demonstrated or because these investigations were carried out on the entire growth in length of the long bone and then the above mentioned variation in rate of growth was partly or entirely eliminated In addition it is conceivable that there is a species variation which may have something to do with the varying nutrition during the age period studied

During the following age period the rate of growth decreases at a different rate in different growth regions The decrease is most pronounced between 40 and 50 days except in the proximal radius where it is most pronounced between 30 and 40 days After this age period the decrease becomes less with the result that the rate of growth during the age period between 60 and 70 days appears to be practically constant especially in the proximal fibula proximal and distal radius while it is somewhat less marked in the proximal tibia and distal tibiofibula

The above mentioned findings correspond well with the results from previous investigations in man (Maresh and Deming 1939 Gill and Abbott 1942 Green and Anderson 1947 Schmid and Kunle 1958 Goff 1960 Tupman 1962 Anderson et al 1963 Tullard and Morscher 1965) and in different experimental animals (Payton 1932 Bisgard and Bisgard 1935 Aries 1941 Sissons 1953 Heikel 1960) but as a rule the methods used did not allow recording of less pronounced variations in rate of growth

In the present investigation it was observed that the rate of growth decreases at different rates in different growth regions which has also been observed by previous investigators (Payton 1932 Bisgard and Bisgard 1935 Gill and Abbott 1942) In the last mentioned investigations it was stated that the decrease occurred more rapidly in the growth regions that grew slowly but in the present investigation the decrease varied partly with growth region and partly with age

It was shown that the percentage of the growth of the diaphysis

varied with age and from one growth region to another which has also been shown by previous investigations (Ollier 1867 Payton 1932 Bisgard and Bisgard 1935 Gill and Abbott 1942 Brodin 1955 Elo 1960) In addition there is probably also a variation with species which is apparent from comparisons of the results obtained in the above mentioned investigations

In the present investigation it was observed that the percentage of growth of the diaphysis from its two growth plates during the first part of the growth period studied is more evenly distributed than during the latter part This has also been observed in previous investigations (Ollier 1867 Payton 1932 Gill and Abbott 1942 Brodin 1955 Elo 1960)

It has previously been assumed that the rate of growth in the major long bones of the lower limbs is highest from the growth plates which are situated near the knee joint while corresponding growth plates in the upper limbs are situated in the proximal humerus and in the distal radius and ulna The present investigation showed that in rabbits this is the case first after about 35 days Before this age growth of the diaphysis of the fibula occurs mainly from the distal growth plate This has previously been reported by Broca (see Ollier 1867) who however used a less reliable method of determination Similar growth has also been recorded for tibia during the prenatal and the earliest part of the postnatal growth period (Bergmann 1929 Bisgard and Bisgard 1935 Caffey 1937 Vahlquist 1943)

The rate of growth from different growth regions in the rabbit has been the subject of several investigations (Sissons 1953 Brodin 1955 Trueta and Amato 1960 Heikel 1960) which have given varying as well as somewhat low values compared with the results in the present investigation This is certainly because different parts of the growth period and different parts of the growth region were examined in the previous investigations In addition it is conceivable that the experimental material varied from one investigation to another

It is difficult to make comparisons between growth in different species because of differences in the duration of the growth period and skeletal development (Heikel 1960) The present investigation however showed that the rate of growth in the rabbit is generally higher than in other species previously examined such as homo (Harris 1926 1931 1933 Gill and Abbott 1942 Green and Anderson 1947 Goff 1960 Anderson et al 1963) dog (Ryöppy 1965) goat (Bisgard and Bisgard 1935) pig (Payton 1932 1933 1934) and rat (Dodds and Cameron

2. EXPERIMENTAL AND CLINICAL INVESTIGATIONS OF THE EFFECT OF SO-CALLED GROWTH-STIMULATING OPERATIONS

The possibility of treating anisomelia by increasing the rate of growth of the shorter limb in relation to that of the longer contralateral limb has been the subject of a large number of clinical and experimental investigations. The methods used have generally been called growth-stimulating, but as mentioned this is to be understood as the increased rate of growth compared with that on the contralateral side.

a. *Operations on Long Bone*

DIAPHYSEAL REGION

Operations on Periosteum

Experimental investigations. Ollier (1867) studied the growth-stimulating effect of periosteal stripping in young rabbits and found that the tibia on the operated side was 2—5 mm longer than that on the other side 3 months after the operation.

The growth-stimulating effect of periosteal stripping has since been demonstrated in several experimental investigations (Wu and Miltner 1937, Lacroix 1947, 1951, Bertrand and Trillat 1948, Brodin 1955, Langenskiöld 1957, Elo 1960, Sola et al. 1963). The strongest stimulation after periosteal stripping has usually been observed during the first weeks after the operation (Lacroix 1947, 1951, Brodin 1955, Langenskiöld 1957, Elo 1960). During the subsequent period the stimulation appears to be less marked (Lacroix 1947, 1951, Brodin 1955, Elo 1960). Brodin (1955) and later Elo (1960) showed that periosteal stripping of the proximal part of the tibial diaphysis retards the growth from the proximal growth region while it stimulates growth from the distal growth region.

Investigations by Wu and Miltner (1937) and Sola et al. (1963) suggest that repeated periosteal stripping probably does not increase the growth-stimulating effect of the first operation.

Periosteal stripping with simultaneous implantation of foreign material (Langenskiöld 1957) or organic tissue (Elo 1960) between the periosteum and the cortex probably produces a slight increase in the growth rate in addition to that brought about by more periosteal stripping.

In those cases where the operation included not only periosteal

stripping but also traumatisation of the perichondrium no stimulation of growth occurred but instead a marked retardation (Ollier 1867 Elo 1960)

Clinical investigations Periosteal stripping has often been used to stimulate growth since the operation is simple and risk free Such an operation usually produces an increase of about 1 cm during the first year after the operation (Bertrand and Trillat 1948 Vieirea and Campa 1956 Taillard 1958 1959 Contessa 1959 Taillard and Morscher 1965)

Operations on Cortical Bone Tissue

Only few investigations have been performed on the growth stimulating effect of operations on the cortical bone

Experimental investigations Bertrand and Trillat (1948) observed that trepanation of the cortical bone tissue in young guinea pigs did not produce any stimulation over and above that of periosteal stripping

Clinical investigations There are probably no clinical investigations of the growth stimulating effect of operations on the corticalis

On the other hand a clinical investigation has been published by Frejka and Fait (1958) who performed stripping of the major part of the periosteum between the growth zones in the tibial diaphysis with exception of the region around the nutrient artery This operation was combined with a number of longitudinal incisions in the corticalis in the middle part of the diaphysis They observed that the postoperative rate of the growth was higher on the operated side compared with that of the contralateral tibia The difference in length was 1—3 cm

Operations on Marrow Cavity

Drilling of Marrow Cavity

The literature contains several reports of the effect of drilling holes in the diaphysis In some investigations large parts of the bone marrow were destroyed while the destruction was probably less in other investigations

Experimental investigations Kishikawa (1936) studied the stimulating effect of a number of drilled holes in the shaft proper and claimed to have demonstrated roentgenologically an increased rate of growth in the operated shaft bone the first few weeks after the operation In later investigations of the effect of drilling holes (Compere and Adams 1937 Hutchinson and Burdeaux 1954 Hansson and Wiberg

1963 Wiberg 1964) and curettage (Wu and Millner 1937) in the metaphyseal area or in the shaft proper have given different results and usually shown only an insignificant effect

Clinical investigations The operations referred to above have also been used in clinical investigations Thus Ferguson (1933) reported that drilling holes in combination with curettage of the corresponding part of the marrow cavity of the proximal tibia and fibula produced a demonstrable stimulation of growth

Later investigations have shown that drilling holes in the diaphyseal region stimulates growth to the same extent as periosteal stripping (Contessa 1959 Taillard and Morscher 1965)

Implantation of Various Substances into the Marrow Cavity

A large number of investigations of the stimulating effect of implantation of different substances into the marrow cavity by different methods have been described and are surveyed below

Experimental investigations The first to use this growth stimulating method was probably von Langenbeck (1869) who implanted ivory pegs into metaphyseal regions of the tibia and femur in a dog He found an increase in growth of about 0 5 cm of both the tibia and femur during the following months

Later a large number of similar investigations were carried out with different substances (Meisenbach 1910 Bohlman 1929 Bergmann 1931 Kishikawa 1936 Wu and Millner 1937 Chapchal and Zeldenrust 1948 Bertrand and Trillat 1948 Herndon and Spencer 1953 Wilson and Percy 1956 Haas 1958) The growth stimulating effect varied widely and sometimes even retardation was observed probably because the operation had traumatised the adjacent growth plate

Trueta (1953 1958) claimed the existence of a correlation between the growth stimulation after implantation of different substances in the marrow cavity and the grade of plugging of the marrow cavity as well as the grade of the periosteal trauma He had previously found that growth stimulation after a diaphyseal fracture like diaphyseal osteomyelitis is usually greatest when the marrow cavity is plugged and that the growth stimulating effect disappears as the marrow cavity again begins to become normal Trueta therefore studied the growth stimulating effect of surgical blocking of the marrow cavity and found that plugging of the marrow cavity with pieces of bone or inert metal with simultaneous traumatisation of the periosteum and destruction of a nutrient artery in the middle part of the diaphysis and

claimed that the operation usually resulted in definite stimulation of growth Trueta (1958) found that denatured bone tissue gave better stimulating effect than vital bone tissue because the blocking of the marrow cavity is longer in the former case

Similar operations have since been performed on rabbits by Langenskiold (1957) and Elo (1960) The former blocked the marrow cavity of the tibia with the aid of a transplant consisting of the proximal fibula and at the same time performed periosteal stripping and implanted subperiosteally a piece of plastic film around the diaphysis Elo on the other hand implanted a piece of skin into the marrow cavity of the proximal tibia of rabbit After both types of growth stimulating operations the rate of growth of the tibia increased on the operated side the first few weeks after the operation

Clinical investigations Several of the foreign substances used in the above mentioned investigations have also been tried clinically The growth stimulating effect has varied widely (Bertrand and Trillat 1948 Pease 1952 Accinno and Parker 1954 Carpenter and Dillon 1956 Jansen 1957 Tupman 1960 Goff 1960 Nordentoft and Guldhammer 1964)

The growth stimulating effect of plugging of the marrow cavity has also been investigated clinically (Stahl 1957 Trueta 1958 Contessa 1959 Taillard and Morscher 1965) The operation has usually comprised extensive periosteal stripping In general the growth stimulating effect was considerable during the first half year after the operation and then decreased relatively quickly (Taillard and Morscher 1965) In those where the operation also included lumbar sympathectomy the stimulation of growth lasted somewhat longer (Stahl 1957)

Fracture and Osteotomy

The growth stimulating effect of the diaphyseal fracture has probably not been used for stimulating growth but in this respect has been substituted by diaphyseal osteotomy On the other hand the diaphyseal fracture has been used in experimental investigations Therefore this type of trauma should be included in the survey of the literature of growth stimulating methods

Experimental investigations In several investigations it has been shown that the rate of growth of a shaft bone with a diaphyseal frac

ture is much higher than that of the contralateral shaft bone (Levander 1929 Bisgard 1936 Bisgard and Martenson 1937 Compere and Adams 1937 Greville and Janes 1957 Wray and Goodman 1961) Bisgard (1936) like Compere and Adams (1937) claimed in contrast with Levander (1929) that the stimulating effect occurs only in the fractured shaft bone while the other shaft bones of the same limb are not affected Later Wray and Goodman (1961) showed that a diaphyseal fracture of the tibia of the rat results in a few days retardation of growth of the femur of both the fractured and the control side on comparison with that in a comparable control series During the following period on the other hand the rate of growth is higher than normal on both sides and especially on the fractured side The final result is thus that the femur on the fractured side is longer than the corresponding shaft bone on the other side

Clinical investigations Goff (1960) reported that he had used splinter osteotomy as a growth stimulating operation which resulted in increased growth in the operated shaft bone during the following 9—12 months The difference achieved between the two sides was usually a few centimetres Blount (1955) reported that multiple osteotomies has a stimulating effect on growth

EPIPHYSEAL REGION

Experimental investigations It has been shown that implantation of pieces of metal for example into the bone epiphysis has no growth stimulating effect but retards growth particularly in those cases where the cartilage plate has been traumatised (Ford and Key 1956 Key and Ford 1958 Haas 1958 Ford and Canales 1960) Haas (1958) reported growth stimulation only in those cases in which he had implanted copper nails into the bony epiphysis and an iron pin in the adjacent metaphysis

Clinical investigations Carpenter and Dalton (1956) implanted iron nails into the epiphyseal area in patients with poliomyelitis with anisomelia but observed only an insignificant stimulating effect

Since inflammation of a joint often has a stimulating effect on the growth of the adjacent regions Bertrand and Trillat (1948) studied the effect of injection of blood into the joint cavity but found no demonstrable stimulating effect on growth

b Operations on Vascular System

ARTERIES

Implantation of Arteries

In recent years several experimental investigations have been carried out in which attempts have been made to increase the arterial flow to one of the growth regions of the shaft bone by implanting the femoral artery into the bone marrow cavity of the diaphysis or into the bony epiphysis of the shaft bone (Woodhouse 1963 Dickerson and Duthie 1963 Boyd and Ault 1965 Del Torto 1965 Dickerson 1966) In these investigations a significant increase in growth was obtained compared to that on the opposite side and to a group of control animals that had been subjected to an incomplete operation which did not include arterial implantation (Dickerson 1966)

Ligation of Nutrient Artery

Ollier (1867) like Wu and Miltner (1937) and Trueta (1953 1958) found no definite stimulating effect of ligation of the nutrient artery On the other hand Brookes (1957) who occluded the nutrient foramen of the femur in newborn rabbits found this operation initially to retard growth on that side This retardation was followed by stimulation and then later by retardation The final result was a somewhat shorter femur on the operated side

Later Troupp (1961) showed that a more proximal ligature such as ligation of the femoral artery usually caused retardation of the growth of the femur and tibia

VEINS

Since the latter part of the 19th century several clinical experimental investigations have been carried out on the effect of venous stasis on the growth in length of the shaft bone In these investigations venous stasis was produced either by ligation of the veins or by application of a tourniquet

Experimental investigations The stimulating effect on venous stasis appears uncertain judging from the results of experimental investigations In various studies no stimulation has been demonstrated (Wu and Miltner 1937 Keck and Kelly 1965) while others have reported a slight stimulation (Pearse and Morton 1930 Bergmann 1931 Kishikawa 1936 Servelle 1948 Hutchinson and Burdeaux 1954 Colt and Iger 1963)

ture is much higher than that of the contralateral shaft bone (Levander 1929, Bisgard 1936, Bisgard and Martenson 1937, Compere and Adams 1937, Greville and Janes 1957, Wray and Goodman 1961). Bisgard (1936) like Compere and Adams (1937) claimed in contrast with Levander (1929) that the stimulating effect occurs only in the fractured shaft bone while the other shaft bones of the same limb are not affected. Later Wray and Goodman (1961) showed that a diaphyseal fracture of the tibia of the rat results in a few days retardation of growth of the femur of both the fractured and the control side on comparison with that in a comparable control series. During the following period, on the other hand, the rate of growth is higher than normal on both sides and especially on the fractured side. The final result is thus that the femur on the fractured side is longer than the corresponding shaft bone on the other side.

Clinical investigations. Goff (1960) reported that he had used splinter osteotomy as a growth stimulating operation which resulted in increased growth in the operated shaft bone during the following 9—12 months. The difference achieved between the two sides was usually a few centimetres. Blount (1955) reported that multiple osteotomies has a stimulating effect on growth.

EPIPHYSEAL REGION

Experimental investigations. It has been shown that implantation of pieces of metal, for example, into the bone epiphysis has no growth stimulating effect but retards growth, particularly in those cases where the cartilage plate has been traumatised (Ford and Key 1956, Key and Ford 1958, Haas 1958, Ford and Canales 1960). Haas (1958) reported growth stimulation only in those cases in which he had implanted copper nails into the bony epiphysis and an iron pin in the adjacent metaphysis.

Clinical investigations. Carpenter and Dalton (1956) implanted iron nails into the epiphyseal area in patients with poliomyelitis with anisomelia but observed only an insignificant stimulating effect.

Since inflammation of a joint often has a stimulating effect on the growth of the adjacent regions, Bertrand and Trillat (1948) studied the effect of injection of blood into the joint cavity but found no demonstrable stimulating effect on growth.

d Physical Methods

ROENTGEN RADIATION

The effect of roentgen radiation on the chondral growth process has been widely studied experimentally It has been shown that the effect varies with the dose small doses to the growth regions often produce brief growth stimulation (Baumach 1935) while somewhat larger doses generally retard growth (Barr et al 1943 Langenskiöld and Edgren 1949 Hulth and Westerborn 1960)

SHORT WAVE DIATHERMY

Experimental investigations Doyle and Smart (1963) reported that moderate doses of short wave diathermy produce a significant stimulation of growth without injuring the cartilaginous growth zone In other experimental investigations however no such stimulation has been found (Granberry and Janes 1963 Schneider 1963) but instead considerable retardation as well as pronounced injury to the cartilaginous growth zone (Wise et al 1949)

Clinical investigations Repeated treatment with short wave diathermy has been tried clinically The stimulation of growth was however only slight (Wilson and Thompson 1939 Bertrand and Tr... 1948)

OTHER PHYSICAL METHODS

In addition to the growth stimulating effect of internal heating (Ring and Lee 1958 Richards and Stofer 1959) ultrasonics (De Forest et al 1953) galvanisation (Paschetta 1949) and direct heat (Fulford and Morscher 1965) have been tried but only internal heating of the area of the diaphysis appears to have stimulating effect

e Mechanical Methods

As mentioned according to Heuter Volkmann's theory longitudinal traction of shaft bones stimulates growth Haas (1958) and Ring (1958) studied this point experimentally but found only a slight increase in length It was also found that the risk of complications by this type of method is considerable

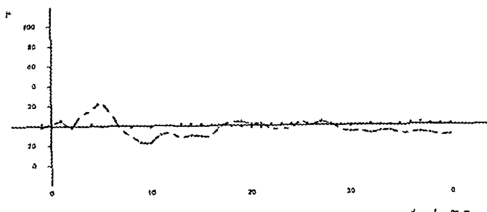


Fig 18 Difference in growth per day between left and right proximal growth plate of tibia after medullary plugging (Table 9)

The growth per day in both series was determined in the way described on page 78 in sections from the following growth regions left and right proximal tibia (fibular part) proximal and distal fibula and the left distal radius

The length of the cell columns was determined in the way described on page 92 in sections of the growth plates in the following growth regions left and right proximal (tibial part) and distal tibia and right distal radius

The material was treated statistically according to the methods given on page 80

2 RESULTS

a *Difference in Rate of Growth and Morphology between Left and Right Sides after Unilateral Plugging of Metaphyseal Marrow Cavity*

RATE OF GROWTH

Proximal Tibia (Table 9 and Fig 18)

On comparison between the left tibia (operated side) and the right tibia (control side) in experimental animals in which the metaphyseal marrow cavity had been plugged it was found that the rate of growth was influenced in a very regular way

During the first 2 postoperative days no significant difference was demonstrable between the rate of growth on the two sides (Fig 19) During the following period until the 6th day the growth per day was

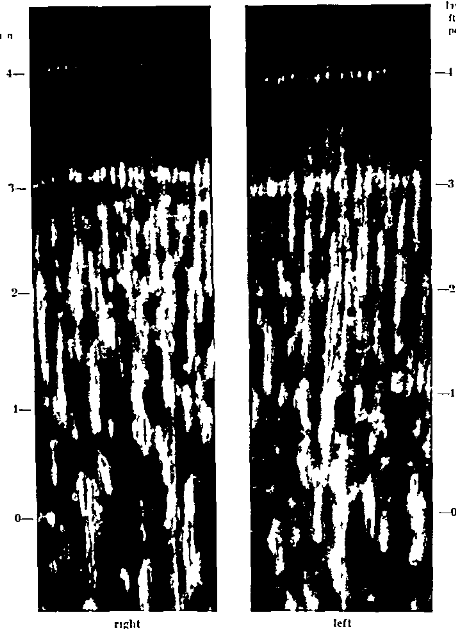


Fig 19 Growth from proximal growth plate of tibia on right and left side during 1st 2nd 3rd and 4th day after medullary plugging (50×)

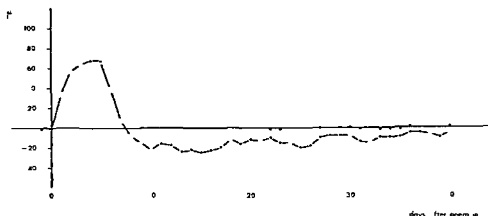


Fig 20 Difference in growth per day between left and right proximal growth plate of fibula after medullary plugging (Table 10)

at most 25 ± 25 μ more on the operated side than on the control side This corresponded to 4 9 % of the rate of growth on the control side During the following 10 days on the other hand the rate of growth was some tens of microns slower on the operated side than on the control side At 60 days and at 80 days after the operation the rate of growth on the operated side was probably lower than on the control side This difference was about 10 % of the rate of growth on the control side

On calculation of the total postoperative difference in growth between the operated and unoperated side it was found that after 6 days the total growth was between about 60—70 μ more on the operated side and this difference represented the maximum value During the following period this difference diminished and the total growth on the control side gradually exceeded that on the operated side Forty days after the operation the total difference was about 105 μ

Proximal Fibula (Table 10 and Fig 20)

Immediately after the operation a difference occurred in the rate of growth per day of the operated and unoperated side The rate of growth on the operated side during the first 7 days was much higher than on the control side with a maximum difference of about 60—70 μ per day during the 3rd—6th day which corresponded to 14—16 % of the growth per day on the control side (Fig 21)

During the 2nd and 3rd week the growth per day on the other hand was some tens of microns slower on the operated side than on

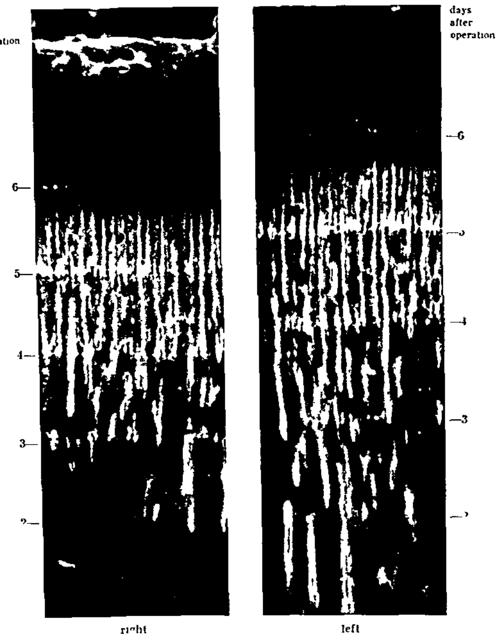


Fig 21 Growth from proximal growth plate of fibula on right and left side during 3rd 4th 5th and 6th day after medullary plugging (50×)

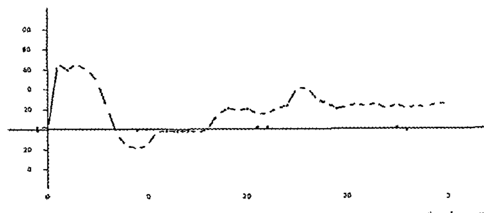


Fig. 22. Difference in growth per day between left and right distal growth plate of fibula after medullary plugging (Table 11)

the control side. During the rest of the observation period the ratio was similar but the difference was as a rule not significant.

The higher rate of growth per day on the operated side resulted in a total postoperative difference of about 331 µ after 7 days. Then the difference diminished so that between 25 and 30 days after the operation the total growth was roughly the same on both sides. During the following period the total growth was larger on the control side than on the operated side and the difference was about 119 µ at 40 days after the operation.

Distal Fibula (Table 11 and Fig. 22)

The growth per day from the distal growth plate of the tibia was not recorded but instead the growth per day from the distal growth plate of the fibula. It is probable that the rate of growth was the same from the distal growth plates of the tibia and of the fibula after the operation as under normal conditions (see page 94). In addition it has been shown previously that the distal tibia and fibula in the rabbit are connected by synostoses between the diaphyses and between the bone epiphyses of which the latter occurs later and at 30—45 days of age (Heikel 1960).

On comparison it was found that during the first postoperative days the rate of growth per day on the operated side was much higher than on the control side. The maximal difference in rate of growth was about 55—70 µ (13—15 %) and was noted during the first 4 days. This was followed by a short period with the reversed ratio. The difference during this period was at most 19 ± 17 µ or 4.2 %. During the

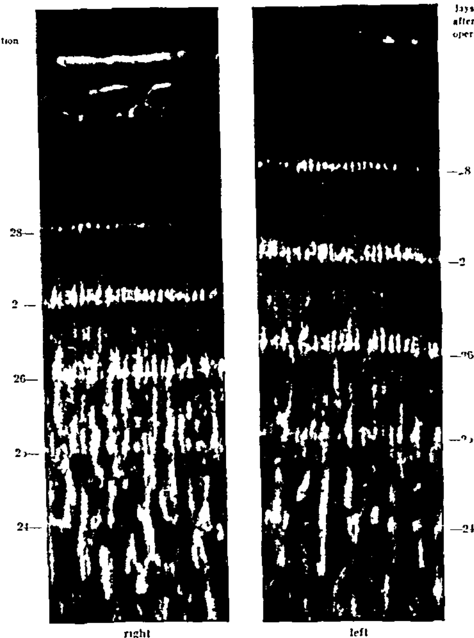


Fig 23 Growth from distal growth plate of fibula on right and left side during 25th 26th 27th and 28th day after medullary plugging (50 ×)

3rd week the ratio changed and the growth was then usually some tens of microns higher on the operated side than on the control side during the following weeks (Fig 23)

The total difference in postoperative growth increased in the distal fibula to reach a maximum after the 6th day when the difference was about 317 μ, i.e. the growth had all together been higher on the operated side than on the control side. During a short period this difference decreased to about 240 μ. Then the total postoperative difference again increased and at 40 days after the operation it was about 793 μ.

Tibial Diaphysis (Table 12)

Since it was possible to determine the growth per day from the proximal and distal growth plates, it was also possible to calculate the total growth of the tibial diaphysis per day.

During the first 6 days after the operation the rate of growth was much higher on the operated side. The difference was greatest on the 3rd postoperative day when it was 76 ± 23 μ. On the 7th day the ratio reversed and during the following 10 days the growth per day was higher on the control side. During the subsequent period until 40 days after the operation the growth per day was often higher on the operated side. These differences were however not always significant. During the rest of the observation period there was no statistically significant difference.

The total difference in growth between the two sides varied with the duration of the postoperative period. After 6 days this difference was about 383 μ and during the following 10 days it decreased to about 200 μ. Then followed a slight increase in the difference from day to day with the result that the total growth after 40 days was about 687 μ higher on the operated side.

Fibular Diaphysis (Table 13)

The rate of growth of the fibular diaphysis during the first 6 days after the operation was 128 ± 27 μ higher on the operated side. During the following 10 days the rate of growth was significantly lower on the operated side. During the rest of the observation period no significant differences were found though the growth per day during the first part was as a rule some tens of microns higher on the operated side.

The total increase in the length of the fibular diaphysis was about 641 μ on the 6th day after which the difference diminished to about 391 μ. It then gradually increased during the following period and on the 40th day after the operation it was about 675 μ.

MORPHOLOGY OF GROWTH REGIONS

General

Already during the first postoperative days a tongue of cartilage cells extending far into the metaphysis from the central part of the growth plate was observed in the proximal growth region of the tibia on the operated side.

Two days after the operation this tongue of cartilage cells (Fig. 24) was almost rectangular in frontal sections. At this time the most metaphyseally situated part extended to the fluorescent band which marked the position of the calcification process at the time of the operation.

The tongue of cartilage cells consisted of hypertrophic cells which were smaller in size than normally, especially in the middle and epiphyseal part of the tongue. In the most metaphyseal part of the tongue the hypertrophic cells were somewhat larger and near the line of erosion single degenerative cells were also seen. The cartilage cells were arranged in columns which could often be traced through the tongue and through that part of the growth plate epiphyseally thereto. The centrally situated cell columns usually ran straight in the longitudinal direction of the long bone, while the peripheral ones were curved with the convexity facing the central part of the tongue.

This picture became less and less marked in direction towards the perichondrial lamella so that the cell columns in the measuring area ran practically straight in the longitudinal direction of the long bone and perpendicular to the line of erosion.

The cell columns in the area measured were not during the first postoperative days of such regular appearance as normally. The length of the cell columns varied more than normally, i.e. fewer cell columns extended from the zone of germinative cells to the line of erosion. The border between the zone of germinative cells and the zone of proliferative cells, like the line of erosion, ran more irregularly than normally.

The metaphyseal trabeculae which were situated diaphyseally to the tongue of cartilage cells appeared delicate and extended further in diaphyseal direction than normally. Between these trabeculae there was usually tissue poor in cells with few osteoblasts and no normal vessels.

Changes were also seen in those parts of the metaphysis bordering the tongue peripherally. The metaphyseal trabeculae in these parts also curved in varying directions. This was most marked nearest the tongue. The operation also appeared to affect the perichondral lamella



Fig 24 Part of proximal growth region of left tibia 2 days after medullary plugging To right growth plate and to left tongue of cartilage cells extending from growth plate into metaphysis (75×)

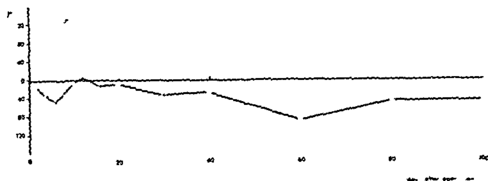


Fig. 25 Difference in length of cell columns between left and right proximal growth plate of tibia after medullary plugging (Table 14)

since here too there was a considerable bending at the level of the tongue of cartilage cells

After 4 days the tongue extended almost twice as far into the metaphysis as 2 days previously which was because the growth plate had in the meantime shifted in epiphyseal direction The metaphyseal border of the tongue was very irregular At this time and also during the following days isolated remnants of the cartilage cell tongue consisting of single hypertrophic and degenerative cartilage cells were observed in the metaphysis at the same as the metaphyseal vessels metaphyseally to the tongue became normal and the trabeculae were covered by osteoblasts

During the following days the metaphyseal and the peripheral parts of the tongue disappeared The last remnants of the cartilage cell tongue disappeared as a rule between 6 and 10 days after the operation From then on the new formed metaphyseal trabeculae were again oriented in the longitudinal direction of the shaft bone

Length of Cell Columns

Besides the above mentioned changes in the morphology of the growth region the operation also affected the length of the cell columns The differences between the growth plates on the operated and unoperated sides are described below

Proximal Tibia (Table 14 and Fig 25)

Two days after the operation no significant difference was found between the operated and the unoperated side but a considerable variation was found between the animals

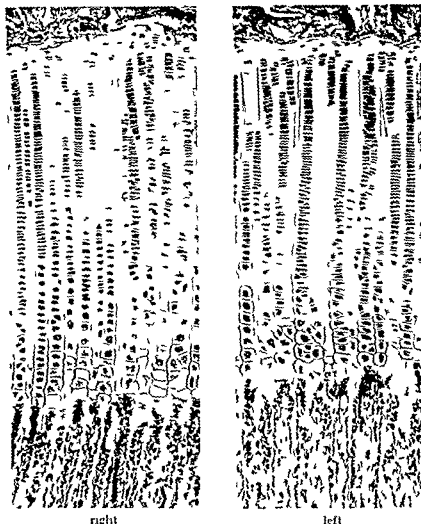


Fig 26 Right and left proximal growth plate of tibia 6 days after medullary plugging (115×)

During the following days on the other hand there was some difference between the sides Four days after the operation the cell columns were 36 ± 28 μ shorter on the operated side This difference was 5.6 % of the length of the cell columns on the control side Two days later the difference was still larger (Fig 26) Eight days after the operation no significant difference was found which also appeared to be the case during the subsequent period

At 60 days after the operation a significant difference of 87 ± 19 μ was found between the sides which corresponds to 14.0 % of the

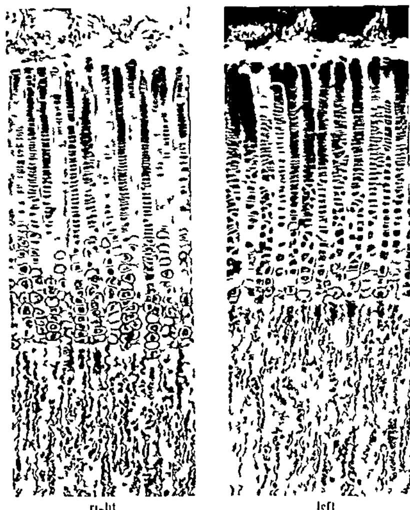


Fig 27 Right and left proximal growth plate of tibia 60 days after medullary plugging (115×)

length of the cell columns on the control side (Fig 27) No significant difference was however found 80 and 100 days after the operation though the difference was about 40—50 μ or 10—12 %

Distal Tibia (Table 15 and Fig 28)

Already 2 days after the operation a difference was found between the length of the cell columns on the two sides (Fig 29) At this time the columns were 53±33 μ or 9.8 % longer on the operated side During the following days the difference persisted practically unchanged

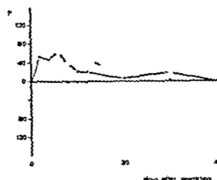


Fig 28 Difference in length of cell columns between left and right distal growth plate of tibia after medullary plugging (Table 1a)

Eight days after the operation there was still an almost significant difference On that occasion the difference was on the average 38 ± 41 μ or 6 8 % of the length of the cell columns on the control side

During the rest of the observation period until 40 days after the operation no significant difference was found between the sides

b *Effect of Plugging of Metaphyseal Marrow Cavity and of Different Steps of Operation on Normal Growth Process*

In the previous section it was shown that plugging of the metaphyseal marrow cavity of the proximal tibia resulted in a difference in rate of growth and morphology between the two sides On the other hand it did not appear possible in that series (series A) to study the way in which the operation affected normal growth It was therefore thought worth while to study the effect of the operation on the growth in members of the same litter rather than to compare the normal series (page 93) and the material from series A In addition it appeared to be of interest to find out what steps of the plugging of the metaphyseal marrow cavity influenced the endochondral growth process

For this purpose the rate of growth and the length of the cell columns were measured in litter mates not subjected to any operation and in litter mates in which the metaphyseal part of the marrow cavity had been plugged or in which only certain steps of the operation had been performed (series B)

As before the previously mentioned differences in growth rate between the sides occurred already during the first postoperative days The growth per day was noted during the day before operation and during the first 4 postoperative days The length of the cell columns was measured at the end of the experimental period

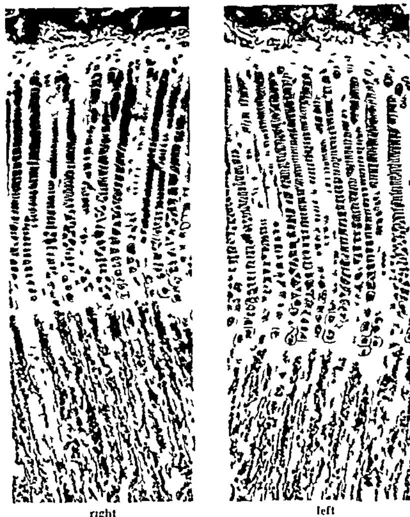


Fig. 29 Right and left distal growth plate of tibia 2 days after medullary plugging (115×)

The normal rate of growth was calculated from the values found in the unoperated animals (Table 16) and on the day before the operation in the operated animals (Tables 17—22) This provided a possibility of calculation the effect of the operation on the normal rate of growth in different growth regions in animals subjected to operations

But this could not be done regarding the length of the cell columns and therefore the length of the cell columns was measured at the end of the experimental period in operated animals and compared with the length found at the same time in the normal material (Tables 23 and 24)

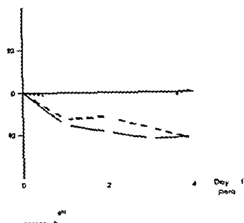


Fig 30 Effect of plugging of marrow cavity on normal growth per day from proximal growth plate of tibia (Table 1)

PLUGGING OF METAPHYSEAL MARROW CAVITY

Rate of Growth (Tables 17 A and B)

Proximal Tibia (Fig 30)

Control side The rate of growth in this growth region was definitely affected by the operation During the first day after the operation growth was on the average 36 µ or 6 3 % less than normal During the following day the rate of growth was roughly the same as that on the first day During the rest of the experimental period growth was more retarded The retardation was about 63 µ (11 3 %) on the fourth day after the operation

Operated side In this growth region daily growth was also markedly retarded during the postoperative observation period The reduction was about 40—60 µ per day or 7—11 % of the normal growth per day

On comparison between the control side and the operated side the growth per day was reduced by practically the same amount except for the second day when the reduction was greater on the operated side On that day this difference between the sides was only 3 5 % of the normal growth

Proximal Fibula (Fig 31)

Control side The growth per day from the growth plate on the control side was definitely reduced during the postoperative period This reduction was least on the second day when it was about 34 µ or 7 1 % while on the fourth day it was about 66 µ or 13 9 % of normal for that day

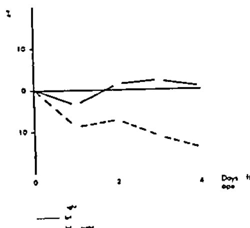


Fig 31 Effect of plugging of marrow cavity on normal growth per day from proximal growth plate of fibula (Table 17)

Operated side During the first postoperative day the reduction in this growth area was on the average 17 µ (3 4 %) During the remaining days growth was normal

The above mentioned varying growth resulted in a difference between the sides increasing from about 27 µ (5 5 %) during the first day to about 70 µ (14 8 %) on the last day

Distal Fibula (Fig 32)

Control side The operation caused a marked reduction in the growth per day in this growth region The reduction was on the average 71 µ per day and was least marked during the second day and most marked on the fourth when it was 14 6 % of normal

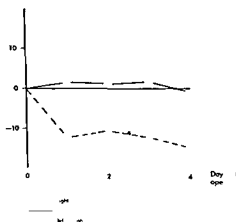


Fig 32 Effect of plugging of marrow cavity on normal growth per day from distal growth plate

mentioned difference between the sides increased during the observation period and on the fourth day it was on the average 53 μ which corresponded to 10.5 % of the normal rate for that day

Proximal Fibula

Control side In this growth region the rate of growth was slightly reduced after the operation

Operated side The operation affected the rate of growth also in this region On the first day the rate of growth was practically normal On the fourth day the rate of growth was on the average 52 μ higher than normal

For all days a significantly higher rate of growth per day was found from the growth plate on the operated side The difference increased from about 30 μ on the first day to about 68 μ on the fourth

Distal Fibula (Fig 36)

Control side During the first three postoperative days the rate of growth per day was significantly lower in this region During this period the rate of growth was retarded by about 25 μ per day which corresponded to about 6 % of the normal rate On the fourth day the rate of growth was not significantly reduced

Operated side In this growth region the rate of growth per day was higher than normal on the second day of observation The difference was most marked on the fourth day *when it averaged 40 μ or 9.5 %* of the normal rate for that day

These changes gave rise to an increasing difference in rate of growth between the sides in the operated animals On the first day it was on the average 33 μ higher on the operated side while on the fourth it was about 58 μ which corresponded to 13.5 % of the normal for that day

Distal Radius

The operation also affected the rate of growth of the anterior limbs of the animals to a certain extent *The rate of growth in the distal* radius was lower than normal on the first postoperative days

Length of Cell Columns

Proximal Tibia (Table 23)

The growth plate on the control side after this operation showed a reduction in length of the cell columns by about 44 μ or 6.4 % but this difference was not significant

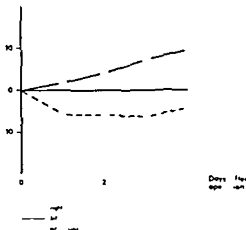


Fig 36 Effect of drilling of corticalis on normal growth per day from distal growth plate of fibula (Table 19)

In contrast to what was seen after the previously mentioned operations this type of operation was not followed by any disturbance of the endochondral calcification and ossification process in the central part of the growth region on the operated side The cell columns on the operated side appeared to be somewhat shorter than normal but this difference was not significant

Neither was any significant difference found between the control side and the operated side though the cell columns were some tens of microns longer in the latter growth region

Distal Radius (Table 24)

In the operated animals the cell columns at the end of the observation period were on the average 43 μ (6 8 %) shorter than normal This difference was almost significant

INCISION OF METAPHYSEAL PERIOSTEUM

Rate of Growth (Tables 20 A and B)

Proximal Tibia (Fig 37)

Control side In this growth region the rate of growth on the first day after the operation was significantly lower than normal On the following days it was practically normal

Operated side Also in this growth region the rate of growth was significantly reduced on the first day after the operation During the following days it became normal and was probably somewhat higher than normal on the third postoperative day

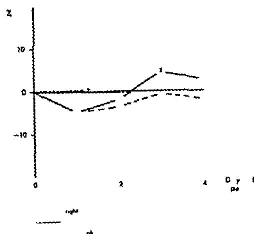


Fig 37 Effect of periosteal incision on normal growth per day from proximal growth plate of tibia (Table 20)

Though the difference was on the average 25 µ (5 %) per day on the last two days of the observation period the difference was not statistically significant

Proximal Fibula

Control side During the first postoperative day the rate of growth in this growth region was lower than normal The reduction on that day was about 22 µ or 5 0 % During the following day no significant change in the rate of growth was observed

Operated side The rate of growth from the growth plate on the operated side varied considerably and during the first day it was somewhat lower than normal and on the following days significantly higher

On comparison between the control side and the operated side it was found that the rate of growth during the postoperative period was probably higher in the latter growth region than in the former The largest difference between the sides per day was on the average 27 µ or 6 1 % of normal which occurred on the last two days

Distal Fibula (Fig 38)

Control side The rate of growth in this growth region was some tens of microns less than normal on the first two postoperative days During the rest of the observation period however no reduction was seen

Operated side In contrast to what was seen on the control side in this growth region it was not possible to demonstrate any significant change in the rate of growth

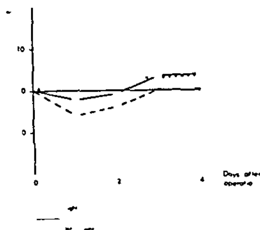


Fig. 38. Effect of periosteal incision on normal growth per day from distal growth plate of fibula (Table 20)

Therefore during the postoperative period the rate of growth was somewhat higher on the operated side than on the control side but the difference was statistically significant only for the first day after the operation

Distal Radius

In this growth region the rate of growth was affected by the operation in largely the same way as in the growth regions of the tibia and fibula on the control side. The rate of growth on the first days was thus significantly lower than normal after which it was largely normal

Length of Cell Columns

Proximal Tibia (Table 23)

The length of the cell columns in the growth plates in the operated and unoperated side was the same as in the normal material

Distal Radius (Table 24)

The cell columns in the growth plate of the distal radius were practically of the same length as normally

INCISION OF SKIN AND ANAESTHESIA

Rate of Growth (Tables 21 A and B, 22 A and B)

Proximal Tibia, Proximal Fibula, Distal Fibula and Distal Radius

During the postoperative observation period no differences were found in the rate of growth from the above mentioned growth regions

after skin incision The anaesthesia during the operation had no effect on the rate of growth either

Length of Cell Columns

Proximal Tibia and Distal Radius (*Tables 23 and 24*)

The length of the cell columns in the two above mentioned growth regions in normals was found to be 687±21 and 640±28 μ respectively at the end of the observation period The corresponding values in the two groups of experimental animals after skin incision and after anaesthesia only did not differ significantly from those found in the normals

3 DISCUSSION

The investigation clearly showed that plugging of the marrow cavity influences endochondral growth an observation in agreement with previous investigations (Trueta 1953 1958 Stahl 1957 Langenskiold 1957 Contessa 1959 Taillard and Morscher 1965)

Investigations of the effect of periosteal stripping of the proximal part of the tibia (Brodin 1955) or the same operation combined with subperiosteal implantation of a skin graft (Elo 1960) showed practically the same effect of the operation on the growth regions of the proximal tibia and the distal tibia as that observed in the present investigation In the above mentioned investigations however the roentgenological method of determination did not allow close analysis of the growth process

In the present investigation medullary plugging in the proximal tibia increased the rate of growth of the tibial diaphysis during the first week after the operation on the operated side compared with that on the control side During the rest of the observation period the difference was much less The total postoperative difference between the sides in growth thus varied with the duration of the observation period The difference between the sides was about 0 4 mm already after the first postoperative week and then varied during the rest of the observation period between 0 2—0 7 mm

This in agreement with what has been reported after periosteal stripping (Lacroix 1947 1951 Brodin 1955 Langenskiöld 1957 Elo 1960) and traumatisation of the marrow cavity (Langenskiold 1957 Elo 1960) in the proximal part of the tibial diaphysis

Previous investigations of the effect of implantation of different sub

stances into the diaphyseal marrow cavity have as mentioned in the survey of the literature given contradictory results These discrepancies between the results can probably be ascribed to different factors

Thus the error of the methods used previously in the determination of growth is more or less equal to the difference recorded between the sides Therefore the results are uncertain

In a large number of investigations (Silfverskiöld 1934 Bisgard and Bisgard 1935 Gill and Abbott 1942 Sissons 1953 Brodin 1955 Heikel 1960 Elo 1960 Rvöppy 1965) of both normal growth and growth after different types of operations growth from different regions of shaft bones has been calculated with the aid of radiopaque indicators implanted into the cortical bone of the diaphysis Such implantation is believed usually not to influence the growth process to any appreciable extent (Bisgard and Bisgard 1935 Brodin 1955 Elo 1960 Rvöppy 1965) However several investigators have observed that the implanted radiopaque marker was inclined to migrate (Silfverskiöld 1934 Bisgard and Bisgard 1935 Rvöppy 1965) In the present investigation it was found that traumatisation of the periosteum and of the cortical bone influenced the rate of growth both locally and generally It is therefore probable that the use of radiopaque indicators for determining growth usually affected the rate of growth and possibly also contributed to the difference between the sides observed after so called growth stimulating operations It should however be mentioned that in these last mentioned investigations radiopaque indicators were usually implanted both on the control side and the operated side so that the effect on growth was probably the same on both sides

The discrepancies between the results may be ascribed to differences in the intervals between the operation and examination of the effect of the operation In the present investigation it was found that the difference between the control side and the operated side varied considerably with the interval after the operation an observation made also by Brodin (1955) and Elo (1960) after periosteal stripping as well as by Blount (1955) and Goff (1960) after diaphyseal fractures in infants

Previous investigations have been carried out on human beings and experimental animals of different ages These differences may also have contributed to the discrepancies between the results According to several investigations (Compere and Adams 1937 Goff 1960 Elo 1960 Tupman 1960 Taillard and Morscher 1965) the effect of the

operation is probably more marked in young than in older growing material

The extent of the operation as well as its site has also varied from one investigation to another and according to Elo (1960) influences the effect of the operation

In many cases where a higher rate of growth has been noted on the operated side than on the control side after implantation of different substances into the marrow cavity it is not possible to exclude subsequent chronic inflammation in the operative region owing to implantation of bacteria or irritating substances into the marrow cavity

Analysis of the literature also revealed that the effect of a so called growth stimulating operation as seen in experimental animals is not always the same as that seen in man This is probably because in most cases the growth rate in the experimental animals is normal on both the operated and control side before the operation while in human beings the operation is usually made in a bone already impaired

As mentioned in the survey of the literature it has been observed that plugging of the marrow cavity at the level of the nutrient canal with simultaneous destruction of the nutrient artery results in an increase in the rate of growth on the operated side compared with that on the other while destruction of the nutrient artery only produces no such effect (Ollier 1867 Wu and Miltner 1937 Trueta 1953 1958 Brookes 1957) The cause of the increase in growth in the former case was believed to be due to the blood supply to the marrow cavity being forced to flow via the metaphyseal perforating arteries for a long time with stimulation of growth as a result (Trueta 1953 1958 Chigot 1958 Taillard and Morscher 1965)

In the light of the results obtained in the present investigation and in previous studies by Brodin (1955) and Elo (1960) the above mentioned explanation of the development of the difference in rate of growth appears improbable It was found in the present investigation that destruction of the vessels in the marrow cavity in the proximal part of the tibial diaphysis with simultaneous plugging produced no increase in the rate of growth from the proximal growth plate of the tibia on the operated side compared with that on the control side except during the latter part of the first week The situation during the following period was the opposite with the result that the total postoperative growth at the end of the observation period was about some hundreds of microns less on the operated side In the growth region of the distal tibia the situation was reversed and the difference

between the sides more pronounced A similar reaction in the proximal and distal growth regions of tibia was observed also after destruction only of the vessels of the marrow cavity in the same part of the diaphysis

When the operation comprised only traumatisation of the cortical bone and the vessels in the marrow cavity were left intact the rate of growth from the distal and proximal growth plates of the tibia was increased which suggests that the vessels must be intact if an operation is to produce a higher rate of growth from the growth plate on the operated side compared with that on the other side This agrees well with the results of previous investigations by Brodin (1955) and Llo (1960)

The present investigation was not intended to elucidate the fate of the implanted homologous bone tissue which will therefore not be discussed here It appears probable however that there is no correlation between the effect on the rate of growth and the resorption of the transplant because the transplant is resorbed slowly and not eliminated until after about a month This has recently been demonstrated by Purranen (1966) who used the tetracycline method in his investigation

Also the growth from the proximal growth plate of the fibula is influenced by plugging of the marrow cavity in the proximal metaphysis of the tibia In this growth region the rate of growth during the first postoperative week was higher on the operated side than on the control side It was evident that the difference in growth per day between the two sides reached its maximum later than in the distal tibio fibula though the maximal difference between the sides appeared to be about the same During the rest of the observation period the difference was insignificant and the rate of growth was usually somewhat higher on the control side

The operation on the tibia results in the diaphyseal part of the fibula increasing about 0 6 mm more in length on the operated side than on the control side during the first postoperative week During the following period this difference is probably reduced at first and later slightly increases since the gain in growth distally is probably not compensated entirely by the loss proximally

The literature contains no investigation of the mode of action of a tibial operation on the growth of the fibula On the other hand it has been observed (Levander 1929 Compere and Adams 1937 Pease 1952 Blount 1955 Wray and Goodman 1961 Guldhammer 1963) that trau

matisation of the tibia or femur usually results in an increased rate of growth of the femur and tibia respectively of the traumatised limb

Elo (1960) found a distinct correlation between the degree of traumatisation and the difference in growth between the two sides which was also found in the present investigation In those cases where the vessels of the growth region were intact the difference in rate of growth during the days following after a more traumatising operation is greater and lasts longer than after a less traumatising one In addition it also appears that the difference in rate of growth during the first day is more pronounced in the distal tibio fibula than in the proximal fibula

The operations resulting in a higher rate of growth on the operated side than on the control side are known in the literature as growth stimulating and it has been assumed that these operations increase the rate of growth on the operated side without affecting other growth regions It has previously however been observed that severe trauma such as a diaphyseal fracture influences the rate of growth both in the traumatised and the opposite limb (Wray and Goodman 1961 Guldhammer 1963 Lacroix 1964) No such observations have been reported in the literature after so called growth stimulating operations

In the present investigation it was found that unilateral plugging of the marrow cavity of tibia caused a reduction in the rate of growth during the first days after the operation not only in the control side but also in the distal radius This retarding effect appeared to be almost equally large in all growth regions and reached 10—15 % of the normal rate of growth

The retarding effect is somewhat less pronounced in those cases where the operation consisted only of destruction of the marrow cavity probably because this operation is less traumatising

Also drilling of the cortical bone and though to a less extent incision of the periosteum cause retardation of growth which however is less pronounced than after the previously mentioned operations On the other hand incision of the skin or anaesthesia had no effect on the rate of growth

Wray and Goodman (1961) observed that a closed fracture of the tibia caused a retardation of the rate of growth of the femur on the opposite side during the first day after the trauma and that the rate of growth during the 2nd and 3rd week was higher than normal The last mentioned effect was also found in the present investigation on comparison with normal material (see page 93) and series A This

observation appears to be uncertain however because the two materials are probably not strictly comparable (see page 100)

On the operated side the effect varied more widely with the type of operation and with the site of the growth region in relation to that of the operation area

Thus it was observed that the rate of growth from the growth plate of the proximal tibia was retarded like that on the opposite side the first few days after plugging of the marrow cavity and after destruction of the marrow cavity On the other hand drilling of the cortical bone and to a less extent incision of the periosteum resulted in a postoperative increase in the rate of growth except during the first day

The rate of growth from the growth region of the distal tibiofibula unlike that in the proximal fibula was not retarded during the first postoperative day but was normal or even higher than normal This explains why the difference in growth per day between the sides the first few days after the operation was more marked for the distal tibiofibula than for the proximal fibula

The morphology of the growth regions was also influenced by the operation on the shaft bone in largely the same way as the rate of growth The cell columns in the proximal growth plate of the tibia during the first few days after marrow plugging as well as after destruction of the marrow cavity in the proximal part of the tibial diaphysis were somewhat shorter on the operated side than on the control side at the same time as the rate of growth was the same or even lower on the operated side This suggests that mitotic activity was lower on the operated side than on the control side the first few days after operation

The difference between the sides disappeared after the first week which suggests that the mitotic activity during the latter part of the first week was higher on the operated side In addition the length of the cell columns as well as the rate of growth was reduced on the operated side compared with the contralateral side 60 days after the operation so that cell production was probably lower in the former growth region

In the distal tibia the situation after marrow plugging was somewhat different In this growth region the mitotic activity was probably higher on the operated side since the rate of growth during the first postoperative week was higher and the cell columns were longer During the following period up to the 40th day after the operation no difference between the sides was found This was probably because the

matisation of the tibia or femur usually results in an increased rate of growth of the femur and tibia respectively of the traumatised limb

Elo (1960) found a distinct correlation between the degree of traumatisation and the difference in growth between the two sides which was also found in the present investigation In those cases where the vessels of the growth region were intact the difference in rate of growth during the days following after a more traumatising operation is greater and lasts longer than after a less traumatising one In addition it also appears that the difference in rate of growth during the first day is more pronounced in the distal tibio fibula than in the proximal fibula

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tioned also been described in previous investigations (Hansson and Wiberg 1963 Wiberg 1964) but this reduction was confined mainly to the zone of proliferative cells while the more metaphyseal part did not appear to be appreciably reduced The difference between the sides was most marked during the first few days after drilling and was usually seen during the first week It was however not possible to decide whether the difference between the sides was due to an increased or reduced rate of growth on the operated side since only the total postoperative difference in length between the sides was recorded

The results obtained in the last mentioned investigations on the effect of drilling agree well with those found in the present investigation after plugging or destruction of the marrow cavity in the proximal part of tibia

There thus appears to be a direct correlation between the morphology of the growth region and the rate of growth also after so called growth stimulating operations which also has been shown previously under other conditions (Harris 1933 Asling et al 1950 Sissons 1953 Johnson 1964)

A cartilaginous growth zone subjected to a so called growth stimulating operation or some other form of trauma is claimed to close earlier than that on the opposite side (Blount 1955 Goff 1960) This is probably not because of an increased rate of growth in this growth region since the rate of growth from the proximal growth plate of the tibia after marrow plugging in the adjacent metaphysis proved to be lower on the operated side than on the control side 100 days after the operation at the same time as the cell columns on the operated side were somewhat shorter At this time i e when the animals were 130 days old the major part of the growth period had elapsed

In previous investigations (Trueta 1958 Trueta and Amato 1960 Trueta 1963 Hansson and Wiberg 1963 Wiberg 1964) as in the present one a tongue of cartilage was seen in the metaphysis after traumatisation of the metaphyseal vessels This tongue developed because the destruction of the degenerative cartilage cells did not proceed at a normal rate Owing to the simultaneous new formation of cells further epiphyseally in the growth plate the cell columns increased in length During the following days the destruction of the degenerative cells again increased as the destroyed metaphyseal vessels regenerated The resorption of the cartilage cells proceeded quicker than the new formation of the cartilage cells and the tongue of cartilage disappeared 6—10 days after the operation

The variation in the orientation of the cell columns and the metaphyseal trabeculae was due to the cells of the tongue developing slower than the corresponding cartilage cells in the more peripheral parts of the growth plate

Opinions differ on the cause of the difference in growth between the sides after a so called growth stimulating operation The difference is usually ascribed to interruption of the metaphyseal blood flow (Ferguson 1933) active hyperemia (Levander 1929 Kishikawa 1936 Bisgard 1936 Bertrand and Trillat 1948 Janes and Musgrove 1950 Trueta 1953 1958 Brodin 1955 Compere 1958 Hiertonn 1961 Sola et al 1963 Woodhouse 1963) or passive hyperemia (Hutchinson and Burdeaux 1954 Hiertonn 1961 Vanderhoeft and Kelly 1964 Keck and Kelly 1965) Other causes have also been suggested (Lacroix 1947 1951 Ring and Ward 1958 Taillard 1959 Ring 1961 Hiertonn 1961 Wray and Goodman 1961)

It appears most probable that operations on shaft bones result in an increased blood flow in the epiphyseal metaphyseal and perichondral vessels with a higher postoperative rate of growth on the operated side as a result Sunden (1967) thus observed a direct correlation between the difference between the sides in rate of growth and in blood flow The same correlation has been observed previously by less refined and less reliable methods (Levander 1929 Brodin 1955 Wray and Lynch 1959 Hulth and Olerud 1960 1961 a and b Wray and Spencer 1960 Wray 1961 Wray and Goodman 1961 Taillard and Morscher 1965 Yabsley and Harris 1965)

Thus much suggests that the blood flow on the operated side is larger than on the control side the first week after marrow plugging destruction of the marrow cavity as well as after drilling of the cortical bone in growth regions with intact vessels The difference between the sides after periosteal incision is probably shorter and less marked

It therefore appears less likely that plugging of the marrow cavity in the proximal tibia increases the blood flow in proximal tibia through the metaphyseal perforating arteries — in contrast to what has been claimed in previous investigations (Trueta 1953 1958 Chigot 1958 Taillard and Morscher 1965) — because the initial difference in rate of growth between the sides was insignificant in the growth region whose metaphyseal vessels were destroyed while the rate of growth from the other growth regions with intact vessels on the operated side was much higher than on the control side The situation is probably similar also after periosteal stripping with injury of the metaphyseal

perforating arteries but not of the metaphyseal vessels from the nutrient artery unless this vessel has been damaged in association with the operation

Wray and Goodman (1961) appear to be the only ones who have previously tried to find out whether traumatisation also influences the growth regions on the control side In their investigation they found that operative traumatisation of a shaft bone not only retarded growth from the growth region on the fractured side but also on the contralateral side This can probably be explained by the assumption that an operation on a shaft bone causes a general impairment of the blood flow which has been shown previously during the first week after severe traumatisation of a shaft bone (Gelin 1956 Bergentz 1961) This effect probably occurs also in the operated limb but it is compensated there entirely or partly by local hyperemia

It is thus clear from the observations in this investigation that it is questionable whether the so called growth stimulating operations which cause a higher rate of growth on the operated side than on the control side can really be regarded as growth stimulating because the difference between the sides after these operations is due to a larger extent to retardation of growth on the unoperated side than to stimulation on the operated side In addition the rate of growth during certain periods after these operations is higher on the operated side and during other periods on the control side

4 SUMMARY

This part of the investigation was concerned with the effect of a so called growth stimulating operation on the growth from different growth plates and on their morphology The experimental animals *i e* young rabbits were divided into two series (A and B) The animals belonging to series A were operated upon at 30 days of age the operation comprising plugging of the marrow cavity in the proximal metaphysis of the tibia with homologous bone tissue

The animals belonging to series B were distributed among seven groups one of which served as a control group and was not subjected to any intervention while other groups were subjected to different types of treatment at 30 days of age The treatment in each group consisted of one or more steps of the operation and ranged from anaesthesia alone to plugging of the marrow cavity

The growth per day from different growth plates was determined

with the aid of OTC in the way described previously during a four (Series A) or five (Series B) day period and the length of the cell columns in the growth plates was studied in the way described previously The observation period for series A ranged from 2 days before *to 100 days after the operation and for series B from 1 day before to* 4 days after the operation

It was found that medullary plugging of the proximal metaphysis of the tibia had a marked and regular effect on the rate of growth and on the length of the cell columns and that this effect varied with growth region and with the interval after the operation

The rate of growth from the proximal growth plate of the tibia during the first few days was practically the same on the operated side as on the control side after which there was a temporary increase in the rate of growth on the operated side During the subsequent period the rate of growth was either higher on the control side or equal on both sides

During the first week the rate of growth from the proximal growth plate of the fibula was higher on the operated side while during the rest of the observation period it was equal on both sides or even lower on the operated side during short periods

The rate of growth during the first week after the operation from the distal tibio fibula was much higher on the operated side after which it was higher on the unoperated side During the latter part of the observation period the rate of growth was lower on the unoperated side

During the first week the cell columns in the proximal growth plate of the tibia were somewhat shorter on the operated side which was also the case during the latter part of the observation period In the growth plate of the distal tibia the situation was different During the first week the cell columns were longer on the operated side after which (up to 40 days) they were equally long on both sides

In the second part of this study (Series B) attempts were made to find out the way in which these differences in rate of growth and length of the columns between the sides developed after marrow plugging

It was found that medullary plugging of the proximal metaphysis of the tibia caused a marked retardation of the rate of growth from the proximal growth plate of the tibia on the operated side during the first few days after the operation The rate of growth from the proximal growth plate of the fibula was also retarded the first day but then became normal During this period the rate of growth from the growth

plates of the distal tibio fibula was normal. The rate of growth from other growth plates outside the operated limb was retarded the first days after the operation.

The same reaction but less pronounced was found also after destruction of the marrow cavity. The rate of growth from the growth plates of the proximal fibula and distal tibio fibula on the operated side was then higher than normal except during the first day.

Drilling of the cortical bone was followed by an increase in the rate of growth from the growth plates on the operated side for the first few days after the operation, while the rate of growth from other growth plates was somewhat retarded during this period. A similar but less pronounced and shorter reaction was observed after periosteal incision, while the incision of the skin, like anaesthesia, produced no demonstrable effect on the rate of growth.

The length of the cell columns varied in practically the same way as the rate of growth.

This part of the investigation thus suggests:

that a so called growth stimulating operation on shaft bones such as medullary plugging has a generalised effect on the rate of growth from different growth plates, which is seen initially as a retardation of the rate of growth;

that the severity and the duration of the general effect vary with the severity of the trauma;

that the generalised effect is partly or entirely compensated on the operated side;

that the effect on the different growth plates on the operated side depends on the severity of trauma, the sites of the growth regions in relation to the operated area as well as the site of the trauma in relation to the vessels in the different growth regions. The length of the cell columns in different growth plates varies in practically the same way as the rate of growth.

GENERAL SUMMARY

The present investigation is concerned with intravital marking of the endochondral calcification process with oxytetracycline (Terramycin®) for determining the growth per day from different growth plates normally and after a so called growth stimulating operation.

Chapter II reports an analysis of the deposition of oxytetracycline in association with the endochondral calcification process in young rabbits which were given 0.5—25 mg oxytretracycline per kg bodyweight intravenously and killed 1 minute—8 days after the injection. The deposition was studied under the fluorescence microscope in sections from material fixed in ethyl alcohol. A method was developed for the preparation of sections and care being taken to minimise the sources of error.

It was found that oxytetracycline is deposited immediately after injection in association with endochondral calcification in the zone of cartilage undergoing calcification. A fluorescent band developed which shifted further into the metaphysis and gradually lost contact with the growth plate because the latter simultaneously shifted in epiphyseal direction. The width of the fluorescent band varied with the dose given and with the rate of growth, while the intensity of the fluorescence varied not only with the dose but also with the age of the animal.

It was found that intravenous doses of 10 and 25 mg oxytetracycline per kg bodyweight often caused pathological changes in the growth regions. The frequency, extent and severity of the changes varied with the dose, rate of growth and probably also with the extent to which the growth regions were loaded.

It proved possible with the use of repeated intravenous injections of 1.0 mg oxytetracycline per kg bodyweight to determine the rate of

growth per day from different growth plates with a precision of 2—4 % of the normal rate of growth per day without any noticeable toxic effect on the rate of growth.

Chapter III is concerned with the normal rate of growth in relation to morphology in different growth regions in animals ranging in age from 20—70 days. It was found that the rate of growth from different growth plates as well as the length of the cell columns varies for different growth plates and with the age of the animals. A close correlation was found between the rate of growth and the length of the cell columns, the correlation varying with age and with growth region.

Chapter IV describes the effect of a so called growth stimulating operation on the rate of growth and morphology of the growth regions. Most of the animals were subjected to plugging of the marrow cavity with homologous bone tissue in the proximal metaphysis of the tibia. Other experimental animals were divided into groups and subjected to only one or more steps of the operation and one group was left intact and served as controls. The growth per day from different growth plates was determined with oxytetracycline and determinations were made of the length of the cell columns.

It was found that plugging of the marrow cavity had marked and regular effect on the rate of growth and on the length of the cell columns, the effect varying with growth plate and interval after the operation.

CONCLUSIONS

1. Oxytetracycline is deposited in association with the endochondral calcification process of shaft bones and when given in large doses it causes pathological changes.

2. Repeated marking of the endochondral calcification process with small doses of oxytetracycline provides a simple, quick and at the same time exact method for determining the rate of growth in length from different growth plates.

3. Normally there appears to be a close correlation between the rate of growth per day and the length of the cell columns.

4. So called growth stimulating operations on shaft bones cause both a generalised and a local effect on the rate of growth and on the length of the cell columns. The difference in growth between the sides is the result of both stimulated and retarded growth.

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TABLES



Table 1 *Methods for Measuring Growth in Length of Shaft Bone*

Type of marker	Technique	Author	Material	Error of method mm
1 no marker	x ray	1957 Langenskiold	rabbit	±1
		1960 Elo		±0.1
		1965 Bullard and Morscher	homo	±1
		1966 Tapp	rat	±0.13
	direct measurement	1957 Greville and Janes	dog	±1
		1958 Ring and Lee	rabbit	±0.5
		1961 Troupp		±0.5
2 anatomical landmarks	x ray	1945 Hendryson	homo	—
		1951 Heikel	rabbit	±0.5
	direct measurement	1916 Digby	homo	—
		1934 Payton	pig	—
		1935 Bisgard and Bisgard	goat	—
3 transverse lines	x ray	1933 Harris	homo	—
		1963 Anderson et al		—
		1963 Guldhammer		—
4 radiopaque indicator	x ray	1955 Brodin	rabbit	±0.3
		1960 Goff	homo	±1.8—10
5 chemically fixed substances				
bismuth	x ray	1937 Caffey	homo	—
		1942 Gill and Abbott		—
lead	x ray	1943 Vahlquist	homo	—
	light microscopy	1957 Amako and Honda	rabbit	—
phosphorus	x ray	1935 Bisgard and Bisgard	goat	—
		1952 Lease	homo	—
	autoradiography	1950 Leblond et al	rat	—
alizarin (madder)	direct measurement	1932 Payton	pig	—
	light microscopy	1941 Arey	rat	—
tetracyclines	fluorescence microscopy	1963 Holmes	calf	—
		1961 Hansson[1]	rabbit	±0.01—0.03
		1968 Tapp	rat	±0.01
H^3 thymidine	autoradiography	1960 Kember	rat	—
6 destruction of metaphyseal vessels	light microscopy	1960 Trueta and Amato	rabbit	—

Table 2 *Error of Determination of Rate of Growth from Proximal Growth Plate of Tibia*

Analysis of Variance

Cause of variation	df	SS	MS	s	F
Between animals	2	38 600	—	—	—
Between right and left growth region	3	100	33 33	[illegible]7	<1([illegible])
Between sections from same growth region	21	4,300	1 9 17	13 1	3 2[illegible] *
Between areas measured in same section	30	1 6[illegible]0	[illegible]00	7 4	1 08([illegible])
Between repeated measurements in same area	60	3 0[illegible]0	[illegible]0 83	7 1	—
Total	119	4 700	—	—	—

Mean growth rate [illegible] μ per day

Table 3 *Error of Determination of Rate of Growth from Proximal Growth Plate of Fibula*

Analysis of Variance

Cause of variation	df	SS	MS	s	F
Between animals	2	3[illegible]830	—	—	—
Between right and left growth region	3	[illegible]10	303 33	1[illegible] 4	4 73**
Between sections from same growth region	[illegible]4	1,240	[illegible]1 [illegible]7	7 2	<1([illegible])
Between areas measured in same section	30	1 0 [illegible]0	3[illegible]6[illegible]	[illegible] 0	<1([illegible])
Between repeated measurements in same area	60	3 [illegible]80	[illegible]	8 0	—
Total	119	3[illegible] 000	—	—	—

Mean growth rate 4[illegible]4 μ per day

Table 4 *Error of Determination of Rate of Growth from Distal Growth Plate of Fibula*

Analysis of Variance

Cause of variation	df	SS	MS	s	F
Between animals	2	44[illegible]0	—	—	—
Between right and left growth region	3	[illegible]0	[illegible]30 00	15 2	2 09([illegible])
Between sections from same growth region	21	[illegible]610	110 00	10 [illegible]	[illegible]**
Between areas measured in same section	30	1 0[illegible]0	3[illegible]6[illegible]	[illegible] 0	<1([illegible])
Between repeated measurements in same area	60	2 4[illegible]0	40 83	[illegible] 8	—
Total	119	[illegible]1 [illegible]00	—	—	—

Mean growth rate 4[illegible]3 μ per day

Table 5 *Rate of Growth per Day from Different Growth Plates*

Day after birth	Rate of growth from proximal growth plate (μ) M	± s	Rate of growth from distal growth plate (μ) M	± s	Rate of growth of diaphysis (μ) M	± s	Rate of growth from proximal growth plate in per cent of rate of growth of diaphysis M	± s
Tibia								
20th	[illegible]4	30	480	41	1 031	70	53 6	0 7
30th	561	30	485	43	1 050	3	53 5	0 9
40th	518	32	436	41	[illegible]	74	[illegible]	0 9
50th	476	28	331	19	760	40	56 1	0 7
60th	[illegible]	[illegible]	[illegible]	26	616	53	58 5	1 1
70th	[illegible]	[illegible]	234	2[illegible]	536	49	60 8	1 5
Fibula								
20th	448	3[illegible]	480	38	[illegible]	73	48 0	0 8
30th	[illegible]	34	485	41	[illegible]	4	49 5	0 7
40th	440	2[illegible]	430	41	[illegible]	62	[illegible]	1 3
50th	368	22	330	20	704	4	52 3	0 7
60th	330	17	272	[illegible]	602	42	54 9	1 4
70th	33[illegible]	[illegible]	234	2[illegible]	566	45	58 7	1 0
Radius								
20th	170	32	444	40	614	57	27 6	3 9
30th	145	14	486	30	631	42	23 0	1 1
40th	90	15	470	35	560	39	17 0	2 7
50th	70	14	40[illegible]	11	472	18	14 7	2 6
60th	34	1[illegible]	358	40	3[illegible]	41	8 7	4 1
70th	30	16	3[illegible]	15	382	32	7 7	3 5

Table 6 *Error of Determination of Length of Cartilage Cell Columns in Proximal Growth Plate of Tibia*

Analysis of Variance

Cause of variation	df	SS	MS	s	F
a Between animals	2	21[illegible] 0[illegible]0	—	—	—
b Between right and left growth region	1	1[illegible]0	120	11 0	<1( )
c Between repeated measurements	1	≈0	≈0	≈0	≈0( )
d Animal × side	2	[illegible]470	3 735	61.2	11 75 **
e Animal occasion of measurement	2	1 110	555	23 6	1 75( )
f Occasion of measurement × side	1	20	20	4.5	<1( )
g Animal side occasion of measurement	2	9 0	485	22 0	1.53( )
h Between sections from same animal side and occasion of measurement	48	17 440	363 33	19 1	1 14( )
i Residual between measurements in same section animal side and occasion of measurement	180	57 230	317 91	17.8	—
Total	239	2[illegible] 4[illegible]0	—	—	—

Error of method calculated from b c d e f g h and i = 18 9 μ

Error of measurement calculated from i = 17.8 μ

Mean length of cartilage cell columns = 680 μ.

Table 7 *Length of Cartilage Cell Columns in Different Growth Plates*

Age in days	Proximal growth plate (μ) M ± s		Distal growth plate (μ) M ± s	
Tibia				
20	[illegible]	[illegible]	—	—
30	[illegible]	[illegible]	621	18
40	709	[illegible]	—	—
50	[illegible]	[illegible]	524	43
60	612	43	—	—
70	591	3	460	10
Radius				
20	212	16	606	63
30	[illegible]	[illegible]	[illegible]	[illegible]
40	[illegible]	[illegible]	631	[illegible]
50	[illegible]	[illegible]	[illegible]	31
60	[illegible]	[illegible]	[illegible]	[illegible]
70	[illegible]	[illegible]	[illegible]	[illegible]

Table 8 *Effect of Various Factors on Normal Rate of Growth from Proximal Growth Plate of Tibia*

Analysis of Variance

Cause of variation	df	SS	MS	[illegible]	F
Between male and female animals	1	[illegible]	288 31	[illegible]	[illegible]
Between litters	5	[illegible]	[illegible]	[illegible]	14 16**
Interaction	5	477 3	[illegible]	[illegible]	[illegible]
Residual	24	3 800	158 33	[illegible]	—

MS values corrected because experimental design was not symmetric (see Snedecor 1962)

Table 9 *Growth in Length from Proximal Growth Plate of Tibia in Series A*

Observation day	Number of animals	Growth per day in microns		Growth per day in per cent of growth of tibial diaphysis per day		*Difference* in growth per day between left and right		*Total post operative difference in growth in length between left and right sides*
		right M±s	left M±s	right M±s	left M±s	μ M±s	% of right	μ
Day before operation								
penultimate	15	5 0±23	568±20	53 5±1.2	53.3±1 2	−2± 4( )	−0 3	—
ultimate	15	561±19	563±19	53 6±1.2	53 6±1 2	2± 4( )	0 4	—
Day after operation								
1st	15	531±24	536±21	51 7±1.2	51 4±1.2	5±12( )	0 5	
2nd	15	527±22	525±22	51 3±1.2	51 1±1 2	−2±1 ( )	−0 4	3
3rd	15	520±28	531±33	51 0±1 6	51 1±1.5	11±16 *	2 1	13
4th	15	511±30	527±31	51 1±1 7	51 6±1 7	16±14 *	3 1	29
5th	15	516±27	541±36	53 1±1 1	51 8±1.5	25±25 *	4 9	5
6th	15	513±28	525±30	52 7±0 8	52.2±1 4	11±14	2 2	66
7th	15	507±3	505±36	53 0±1.2	53 2±1.3	−3±15( )	−0	63
8th	1	507±39	497±41	52 9±1 4	3 4±1 3	−10± 9***	−2 0	3
9th	12	518±40	501±50	53 4±1 4	53 7±1 4	−17±14	−3 2	37
10th	12	521±33	503±45	53 ±1.3	53 6±1 3	−18±17*	−3 5	18
11th	11	531±23	522±31	53 6±1 0	53 4±0 6	−9±14( )	−1 7	9
12th	11	519±26	512±32	53 6±0 9	53 4±0 7	−7±13( )	−1 4	2
13th	13	520±37	508±44	54 1±1 3	53 7±1 0	−12±15	−2 2	−10
14th	13	515±26	506±29	54.2±1.3	53 9±0 9	−9±12*	−1 8	−15
15th	10	502±28	492±32	54 6±1 0	4.3±0 8	−10±12*	−2 0	−29
16th	10	491±17	481±19	54 6±1 0	54 2±1 1	−10±11*	−1 2	−39
17th	5	472±55	472±58	55 4±1 2	55 5±1 4	0± 7( )	0 0	−39
18th	5	468±48	472±51	55 9±1 5	54 7±1 4	4± 5( )	0 9	−35
19th	5	464±36	468±40	56 8±0 7	7±1.3	4± 5( )	0 9	−31
20th	5	448±53	450±55	57 0±0 4	55 7±1 0	2± 4( )	0 4	−29
21st	4	475±31	4 8±30	56 4±1 0	55 6±1 0	3± 5( )	0	−26
22nd	4	468±36	465±39	56 4±0 7	5 2±0 6	−3± ( )	−0 5	−29
23rd	4	463±39	460±41	55 9±0 9	54 4±0 5	−3± 5( )	−0 5	−31
24th	4	460±34	458±36	56.3±1 1	54 6±0 7	−3± 5( )	−0 5	−34
25th	4	428±19	433±29	56 5±1 6	53 9±0 9	±17( )	1 2	−29
26th	4	430±22	430±29	57 2±1 6	54.3±1 0	0±16( )	0 0	−29
27th	5	454±36	458±37	56 2±0 4	54 6±0 8	4±15( )	0 9	−25
28th	5	450±34	452±31	56 6±0 8	54 9±1 5	2±11( )	0 4	−23
29th	5	452±31	448±35	56 6±1 1	55 0±1 4	−4± ( )	−0 9	−27
30th	5	446±27	440±28	56 9±0 7	54 9±1 1	−6± 5( )	−1 3	−33
31st	4	433±74	428±74	57 0±0 9	54 9±0 6	−5± 6( )	−1 2	−38
32nd	4	425±68	418±69	57 1±1 1	5 0±1 3	−8±10( )	−1 8	−45
33rd	4	423±46	418±52	57 9±2 3	55 7±2 4	− ± 6( )	−1 2	−50
34th	4	425±48	420±54	57 9±2 4	56 0±2 4	−5± 6( )	−1 2	−55
35th	4	408±39	400±47	57 8±3 5	55 3±2.3	−8±10( )	−1 8	−63
36th	4	400±24	393±33	57 9±3 2	55 7±1 9	−8±10(−)	−1 9	−70
37th	6	402±22	395±27	57 8±1 4	55 5±1 2	−7±10(−)	−1 7	−77
38th	6	390±24	382±30	57 9±1 0	55 5±1.3	−8±10( )	−2 1	−85
39th	4	390±32	380±32	59 4±0 8	56 4±1 2	−10±12( )	−2 6	−95
40th	4	385±26	375±27	58 8±1 2	55 9±1 4	−10±12( )	−2 6	−105
57th–60th incl	3	308±12	274±18	64 1±0 9	59 6±1 7	−33±12*	−10 8	—
77th–80th incl	3	223±22	201±25	69 0±2 4	63 5±2 6	−22± 5*	−9 8	—
97th–100th incl	3	132±40	124±43	81 4±5 9	76 1±9 0	−8± 9( )	−5	—

Table 10 *Growth in Length from Proximal Growth Plate of Fibula in Series A*

Observation day	Number of animals	Growth per day in microns		Growth per day in per cent of growth of tibial diaphysis per day		Difference in growth per day between left and right		Total postoperative difference in growth in length between left and right sides
		right M±s	left M±s	right M±s	left M±s	μ M±s	% of right	μ
Day before operation								
penultimate	15	463±16	465±16	48.3±1.3	48.3±1.1	2± 4( )	0.4	—
ultimate	15	463±24	462±25	48.8±1.2	48.6±1.4	−1± 3( )	−0.2	—
Day after operation								
1st	15	438±23	471±22	49.9±1.2	48.2±1.0	33±11***	7.6	33
2nd	15	443±30	499±32	44.9±1.4	49.8±0.9	56±21**	12.6	89
3rd	15	437±25	499±26	49.7±1.4	49.6±1.0	63±15***	14.4	152
4th	15	429±25	496±31	49.6±1.4	50.1±1.3	67±19***	15.7	219
5th	15	427±21	495±36	48.4±1.1	49.6±1.2	67±19***	15.8	286
6th	15	433±2[illegible]	471±21	48.4±0.8	49.5±1.3	38±13***	8.8	325
7th	15	427±36	433±36	48.7±1.0	49.4±1.0	6±11*	1.4	331
8th	15	431±31	423±37	48.8±1.2	49.3±1.2	−8±13*	−1.9	323
9th	12	440±36	425±46	49.4±1.4	49.6±1.2	−15±15*	−3.4	308
10th	12	451±32	428±40	49.5±1.0	49.6±1.1	−23±15**	−5.0	285
11th	11	460±18	444±19	50.0±1.4	49.2±1.1	−16±13**	−3.6	269
12th	11	454±[illegible]0	435±24	[illegible]0.3±1.3	49.4±1.1	−18±15**	−4.0	251
13th	13	448±31	425±42	50.4±1.2	49.2±0.8	−24±14***	−5.3	227
14th	13	443±30	422±33	50.4±1.2	49.3±1.0	−22±16***	−4.9	205
15th	10	429±31	404±29	50.6±1.1	49.3±1.2	−25±14***	−5.8	180
16th	10	426±21	403±21	51.1±1.1	49.[illegible]±1.0	−23±14*	−5.4	157
17th	5	418±41	398±43	5[illegible].5±1.5	[illegible]0.3±1.1	−20±10*	−4.8	137
18th	5	410±3[illegible]	398±43	52.7±2.0	50.[illegible]±1.4	−12± 8	−2.9	125
19th	5	414±29	398±37	51.0±0.8	51.7±0.9	−16±11*	−3.9	109
20th	5	396±46	384±48	54.0±0.5	51.[illegible]±1.1	−12± 8*	−3.0	97
21st	4	423±40	410±36	53.5±0.7	51.8±0.6	−13±10( )	−3.0	85
22nd	4	415±38	405±31	53.4±1.0	51.8±1.1	−10± 8( )	−2.4	75
23rd	4	408±42	393±40	52.8±1.3	50.5±1.3	−15±13( )	−3.7	60
24th	4	405±38	390±35	53.1±1.0	50.[illegible]±1.8	−15±13( )	−3.7	45
25th	4	383±55	363±17	53.7±1.1	49.5±2.0	−20±15( )	−5.2	25
26th	4	380±26	363±17	51.1±0.8	50.1±1.7	−18±15( )	−4.6	7
27th	5	402±2[illegible]	392±31	53.2±1.3	50.[illegible]±1.3	−10±10( )	−2.5	−3
28th	5	394±34	386±34	53.2±1.0	51.0±1.4	−8± 4	−2.0	−11
29th	5	400±23	392±27	53.6±1.2	51.7±1.3	−8± 8( )	−2.0	−19
30th	5	400±26	392±30	51.1±1.0	52.0±1.0	−8± 8( )	−2.0	−27
31st	4	395±63	380±63	54.8±1.0	51.9±1.0	−15±13	−3.8	−42
32nd	4	393±5[illegible]	3[illegible]8±[illegible]6	55.2±1.1	52.6±1.5	−15± 6*	−3.8	−57
33rd	4	3[illegible]8±52	368±50	55.1±1.8	52.5±1.9	−10± 8( )	−2.6	−67
34th	4	3[illegible]5±47	365±52	51.8±1.3	52.6±1.9	−10± 8( )	−2.7	−77
35th	4	363±36	353±43	51.9±1.1	55.1±1.6	−10± 8( )	−2.8	−87
36th	4	358±35	353±36	55.1±1.1	53.0±1.5	−5± 6( )	−1.4	−92
37th	6	358±21	353±18	55.0±1.8	52.7±1.1	−5± 8( )	−1.4	−97
38th	6	318±25	312±21	55.1±1.5	52.8±1.1	−7±12( )	−1.9	−104
39th	4	345±24	335±17	56.4±1.7	53.4±1.3	−10±14( )	−2.9	−114
40th	4	343±29	338±25	56.0±1.5	53.4±1.6	−5± 6( )	−1.5	−119
57th–60th incl	3	276±13	257±18	61.5±1.1	58.0±1.8	−19±12( )	−7.0	—
77th–80th incl	3	209±21	203±[illegible]	67.6±2.4	63.7±2.9	−7± 8( )	−3.2	—
97th–100th incl	3	136±47	127±47	81.8±5.3	76.4±8.7	−9± 9( )	−6.8	—

Table 11 *Growth in Length from Distal Growth Plate of Fibula in Series A*

Observation day	Number of animals	Growth per day in microns		Difference in growth per day between left and right		Total post operative difference in growth in length between left and right sides
		right M ± s	left M ± s	μ M ± s	% of right	μ
Day before operation						
penultimate	15	497 ± [illegible]3	498 ± [illegible]	2 ± [illegible]	0 3	—
ultimate	15	487 ± [illegible]3	489 ± 21	[illegible] ± [illegible]	0 [illegible]	—
Day after operation						
1st	15	440 ± 15	[illegible]	[illegible]	1[illegible]0	[illegible]
2nd	15	444 ± 23	[illegible]03 ± 28	[illegible]9 ± 16	13 4	12[illegible]
3rd	15	443 ± 33	508 ± 31	[illegible] ± 1[illegible]	14 8	[illegible]
4th	15	43[illegible] ± [illegible]	[illegible]91 ± 31	[illegible]9 ± 20***	13 [illegible]	[illegible]49
5th	15	4[illegible]7 ± 28	[illegible]03 ± 44	47 ± [illegible]3***	10 2	[illegible]
6th	15	461 ± 29	481 ± 38	21 ± 17***	4 [illegible]	317
7th	15	4[illegible]1 ± 49	44[illegible] ± 49	−6 ± 13( )	−1 [illegible]	311
8th	15	4[illegible]3 ± [illegible]	436 ± [illegible]3	−1[illegible] ± 13***	−3 8	[illegible]
9th	12	4[illegible]2 ± 46	433 ± [illegible]	−19 ± 1[illegible]**	−4 2	[illegible]
10th	12	4[illegible]3 ± 4[illegible]	437 ± [illegible]	−17 ± 17**	−3 7	2[illegible]8
11th	11	460 ± 32	4[illegible] ± 31	−4 ± 8( )	−0 8	[illegible]
12th	11	449 ± 3[illegible]	446 ± 33	−3 ± [illegible]( )	−0 [illegible]	[illegible]
13th	13	442 ± 4[illegible]	439 ± 41	−3 ± [illegible]( )	−0	[illegible]48
14th	13	437 ± 33	431 ± 31	−3 ± 8( )	−0 7	[illegible]
15th	10	418 ± 29	414 ± 27	−4 ± 7( )	−1 0	[illegible]
16th	10	408 ± 21	407 ± 20	−1 ± 6( )	−0 1	[illegible]
17th		380 ± 48	394 ± [illegible]1	14 ± [illegible]**	3 7	[illegible]
18th	[illegible]	3[illegible]0 ± 5[illegible]	390 ± 4[illegible]	20 ± 12*	5 4	[illegible]
19th	[illegible]	3[illegible]4 ± 3[illegible]	372 ± 29	18 ± 13*	[illegible]1	[illegible]
20th	[illegible]	339 ± 53	[illegible] ± 37	20 ± 10 *	5 9	[illegible]
21st	4	368 ± 38	383 ± 3[illegible]	1[illegible] ± 13( )	4 1	[illegible]
22nd	4	363 ± 34	378 ± 39	1[illegible] ± 13( )	4 1	[illegible]
23rd	4	36[illegible] ± 33	38[illegible] ± 31	20 ± 1[illegible]( )	[illegible]	[illegible]
24th	4	3[illegible]8 ± 33	380 ± 3[illegible]	[illegible]3 ± 10*	6 [illegible]	[illegible]
25th	4	330 ± 23	370 ± 3[illegible]	40 ± 14*	1[illegible] 1	[illegible]
26th	4	323 ± [illegible]	363 ± 38	40 ± 18*	1[illegible] 4	[illegible]
27th	[illegible]	3[illegible]4 ± 32	382 ± 39	28 ± 19*	7 9	[illegible]
28th	[illegible]	346 ± 32	3[illegible] ± 39	[illegible]6 ± 19*	7	[illegible]
29th		34[illegible] ± 24	36[illegible] ± 27	[illegible]0 ± 7**	5 8	[illegible]
30th	5	340 ± 27	362 ± 30	22 ± 4***	6 [illegible]	[illegible]
31st	4	3[illegible]8 ± 63	3[illegible]3 ± 6[illegible]	[illegible] ± 10*	7 [illegible]	[illegible]
32nd	4	3[illegible]0 ± [illegible]7	313 ± [illegible]8	23 ± 13*	7 0	[illegible]
33rd	4	310 ± [illegible]8	33[illegible] ± 66	[illegible] ± 10*	8 1	[illegible]
34th	4	313 ± 61	333 ± 68	20 ± 8*	[illegible] 4	[illegible]
35th	4	300 ± [illegible]	3[illegible] ± [illegible]	2[illegible] ± 24( )	[illegible]	[illegible]
36th	4	293 ± 43	313 ± 40	[illegible]0 ± 2[illegible]( )	[illegible]	[illegible]
37th	6	[illegible]93 ± 19	317 ± 14	23 ± 1[illegible]*	[illegible]	[illegible]
38th	[illegible]	[illegible]83 ± 19	30[illegible] ± 10	22 ± 15*	[illegible]	[illegible]
39th	4	268 ± 2[illegible]	293 ± 1[illegible]	2[illegible] ± 13*		[illegible]
40th	4	2[illegible]0 ± 29	29[illegible] ± 24	2[illegible] ± 13*		[illegible]
57th–60th incl	3	173 ± 7	186 ± [illegible]	13 ± [illegible]		
[illegible]th–80th incl	3	101 ± 21	117 ± [illegible]7	16 ± [illegible]		—
97th–100th incl	3	33 ± 20	43 ± 33	11 ± [illegible]		

Table 12 *Growth of Tibial Diaphysis in Series A*

Observation day	Number of animals	Growth per day in microns		Difference in growth per day between left and right		Total post operative difference in growth in length between left and right sides
		right M±s	left M±s	μ M±s	% of right	μ
Day before operation						
penultimate	15	1 067±38	1 064±36	0±6( )	0.0	—
ultimate	15	1 018±30	1 022±30	4±7( )	0.4	—
Day after operation						
1st	15	971±31	1 042±44	71±21 **	7.3	71
2nd	15	971±38	1 028±44	57±1[illegible] **	5.9	128
3rd	15	963±53	1 039±57	76±23***	7.9	204
4th	15	946±51	1 021±55	75±23**	7.9	279
5th	15	9[illegible]3±[illegible]	1 015±75	72±42 **	7.4	351
6th	15	974±58	1 006±67	32±21	3.3	383
7th	15	958±89	949±88	−9±[illegible]( )	−0.9	374
8th	15	961±96	933±98	−27±21**	−2.8	347
9th	12	969±83	933±102	−36±27***	−3.7	311
10th	12	974±77	939±98	−35±30	−3.6	276
11th	11	991±54	979±61	−12±16*	−1.2	264
12th	11	968±57	958±64	−10±13*	−1.0	254
13th	13	962±80	948±86	−15±19*	−1.5	240
14th	13	952±54	940±[illegible]	−12±15*	−1.3	227
15th	10	920±51	906±57	−16±14**	−1.7	211
16th	10	899±33	888±31	−11±12*	−1.2	200
17th	5	852±102	866±105	14± 9*	1.6	214
18th		838±98	862±90	24± 9**	2.9	238
19th	5	818±71	840±66	22± 8 *	2.7	260
20th	5	786±95	808±91	22± 8**	2.8	282
21st	4	843±68	860±65	18±10*	2.1	300
22nd	4	830±62	843±77	13±15( )	1.5	312
23rd	4	828±70	845±71	18±13( )	2.1	330
24th	4	818±65	839±67	20± 8*	2.4	350
25th	4	758±36	803±[illegible]9	45±30( )	5.9	395
26th	4	753±43	793±67	40±27( )	5.3	435
27th	5	808±68	840±75	32±33( )	4.0	467
28th	5	796±65	824±67	28±29( )	3.5	495
29th	5	798±52	814±58	16±11*	2.0	511
30th	5	786±54	802±56	16± 5**	2.0	527
31st	4	760±137	780±140	0±14( )	2.6	547
32nd	4	745±124	760±130	15±10( )	0	562
33rd	4	733±103	753±116	20±14( )	2.7	582
34th	4	738±108	753±120	15±13( )	2.0	597
35th	4	[illegible]08±88	725±94	18±31( )	2.5	614
36th	4	693±60	[illegible]05±69	13±30( )	1.8	627
37th	6	695±36	712±37	17±21( )	2.4	643
38th	6	673±40	687±39	13±21( )	2.0	657
39th	4	658±43	673±45	15±13( )	2.3	672
40th	4	655±55	670±58	15±13( )	2.3	687
57th–60th incl	3	480±15	460±19	−20±10( )	−4.2	—
77th–80th incl	3	323±43	318±51	−6±10( )	−1.8	—
97th–100th incl	3	161±60	168±74	3±16( )	2.0	—

Table 13 Growth of Fibular Diaphysis in Series 1

Observation day	Number of animals	Growth per day in microns: right M±s	Growth per day in microns: left M±s	Difference in growth per day between left and right: μ M±s	Difference in growth per day between left and right: % of right	Total post-operative difference in growth in length between left and right sides: μ
Day before operation						
penultimate	15	960±31	963±31	3±[illegible]( )	0.3	—
ultimate	15	950±42	951±41	1±3( )	0.1	—
Day after operation						
1st	15	878±33	9[illegible]±47	99±2[illegible]*	11.3	99
2nd	15	887±48	1 003±57	115±31*	13.0	215
3rd	15	870±53	1 007±54	128±27**	11.6	313
4th	1[illegible]	864±49	990±59	126±33* *	14.6	4[illegible]
5th	15	894±49	998±7[illegible]	114±40*	12.[illegible]	583
6th	1[illegible]	893±[illegible]4	952±56	59±20* *	6.6	641
7th	1[illegible]	878±83	8[illegible]8±81	0±23( )	0.0	641
8th	1[illegible]	894±87	859±69	−25±18 *	−2.9	616
9th	12	892±78	858±99	−34±28	−3.8	[illegible]92
10th	12	904±[illegible]6	865±94	−39±30**	−4.3	[illegible]43
11th	11	920±46	900±46	−20±17 *	−2.2	523
12th	11	903±48	882±54	−21±16	−2.3	502
13th	13	891±81	864±85	−27±[illegible]	−3.0	475
14th	13	890±53	855±61	−35±18**	−2.8	450
15th	10	847±57	818±53	−29±15***	−3.4	421
16th	10	834±38	810±3[illegible]	−24±17 *	−2.9	39[illegible]
17th		798±86	792±92	−6±15( )	−0.8	391
18th	5	780±84	788±82	8±11( )	1.0	399
19th	5	768±64	770±65	2±13( )	0.3	401
20th	5	734±85	742±84	8±8( )	1.1	409
21st	4	790±77	793±71	3±21( )	0.3	412
22nd	4	778±[illegible]0	783±69	5±13( )	0.6	417
23rd	4	773±73	778±68	5±1[illegible]( )	0.6	422
24th	4	763±70	770±61	8±17( )	1.0	429
25th	4	713±46	733±41	20±16( )	2.8	449
26th	4	703±51	725±53	23±22( )	3.2	4[illegible]2
27th		756±56	774±67	18±1[illegible]( )	2.4	490
28th	5	740±64	758±70	18±18( )	2.4	508
29th	5	746±44	758±50	12±13( )	1.6	520
30th	5	740±51	754±59	14±11( )	1.9	534
31st	4	723±127	733±129	10±22( )	1.4	544
32nd	4	713±114	720±123	8±13( )	1.1	551
33rd	4	688±109	703±115	15±13( )	2.2	566
34th	4	688±108	698±119	10±14( )	1.5	576
35th	4	663±85	678±93	15±26( )	2.3	591
36th	4	650±67	665±73	15±19( )	2.3	606
37th	6	652±33	670±28	18±20( )	2.8	625
38th	6	632±39	647±29	15±21( )	2.4	640
39th	4	613±41	628±28	15±24(−)	2.4	655
40th	4	613±56	633±44	20±18( )	3.3	675
57th–60th incl	3	448±16	443±19	−6±11( )	−1.3	—
77th–80th incl	3	310±41	319±50	9±12(−)	3.0	—
97th–100th incl	3	168±67	170±78	2±14(−)	1.0	—

Table 14 *Length of Cell Columns in Proximal Growth Plate of Tibia in Series 1*

Interval between operation and sacrifice (days)	Number of animals	Length of cell columns (μ)		Difference between left and right	
		right M ± s	left M ± s	μ M ± s	% of right
2	6	654 ± 4[illegible]	631 ± 61	−19 ± 30( )	−4.9
4	9	650 ± 55	613 ± 43	−36 ± [illegible]8**	−5.6
6	6	670 ± 31	622 ± 33	−47 ± [illegible]6*	−7.1
8	9	[illegible]6 ± 55	659 ± 6[illegible]	−2[illegible] ± 40( )	−3.8
10	6	68[illegible] ± 5[illegible]	680 ± 6[illegible]	−7 ± 30( )	−1.1
12	6	[illegible]22 ± 85	[illegible]6 ± 94	4 ± 66( )	0.5
14	5	[illegible]0 ± [illegible]	703 ± 56	−3 ± 19( )	−0.5
16	8	681 ± 48	668 ± 38	−13 ± [illegible]4( )	−1.9
20	3	6[illegible]0 ± 101	641 ± 101	−8 ± [illegible]0( )	−1.3
30	3	663 ± 30	631 ± 37	−32 ± 21( )	−4.8
40	4	615 ± 31	5[illegible]3 ± 45	−[illegible]6 ± 31( )	−4.1
60	3	581 ± 42	497 ± 25	−87 ± 19	−14.9
80	3	45[illegible] ± 51	408 ± 44	−44 ± 19( )	−[illegible].8
100	3	366 ± 43	3[illegible]0 ± [illegible]0	−45 ± 21( )	−12.4

Table 15 *Length of Cell Columns in Distal Growth Plate of Tibia in Series 1*

Interval between operation and sacrifice (days)	Number of animals	Length of cell columns (μ)		Difference between left and right	
		right M ± s	left M ± s	μ M ± s	% of right
2	4	5[illegible]3 ± 30	[illegible]90 ± 16	53 ± 33*	9.8
4	[illegible]	538 ± [illegible]6	585 ± 54	47 ± 16***	8.[illegible]
6	4	54[illegible] ± 5[illegible]	611 ± 40	64 ± 32*	11.7
8		562 ± 4[illegible]	600 ± 35	38 ± 41	6.8
10	5	569 ± 43	590 ± 41	[illegible]1 ± [illegible]( )	3.6
12	3	630 ± 69	650 ± [illegible]4	20 ± 22( )	3.2
20	5	515 ± 79	520 ± 75	[illegible] ± 21( )	1.1
30	3	525 ± 31	543 ± 16	18 ± 16( )	3.5
40	4	495 ± 16	495 ± 15	0 ± 8( )	0.1

Table 16 *Growth per Day from Different Growth Plates in Group 1 (Controls) in Series B*
Number of Animals 9

Day after birth	Proximal tibia (μ)				Proximal fibula (μ)				Distal fibula (μ)				Distal radius (μ)	
	Growth per day		Change in relation to that on 30th day		Growth per day		Change in relation to that on 30th day		Growth per day		Change in relation to that on 30th day		Growth per day	Change in relation to that on 30th day
	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	left M±s	left M±s
30th	553±33	551±38	—	—	463±31	465±31	—	—	4[illegible]±38	4[illegible]6±34	—	—	1[illegible]±33	—
31st	544±42	544±41	−9±6	−7±7	455±31	462±31	−1±[illegible]	−1±[illegible]	466±38	467±3[illegible]	−1±3	1±8	171±32	−1±7
32nd	541±35	541±38	−12±8	−10±7	453±27	458±28	−9±[illegible]	−10±10	462±38	464±3[illegible]	−1±[illegible]	−1±6	180±30	1±[illegible]
33rd	532±34	532±35	−21±12	−19±12	450±23	452±25	−13±12	−11±10	461±35	466±35	−1[illegible]±13	−10±14	1[illegible]±23	0±11
34th	531±27	532±9	−22±17	−[illegible]±15	449±21	452±	−14±16	−11±14	463±31	462±30	−13±16	12±20	1[illegible]2±21	−7±1[illegible]

Table 19 A *Growth per Day from Different Growth Plates in Group 4 (Drilling of Corticalis) in Series B*

Number of Animals 4

Day after birth	Proximal tibia (μ)				Proximal fibula (μ)				Distal fibula (μ)				Distal radius (μ)	
	Growth per day		Change in relation to that on 30th day		Growth per day		Change in relation to that on 30th day		Growth per day		Change in relation to that on 30th day		Growth per day	Change in relation to that on 30th day
	right M ± s	left M ± s	right M ± s	left M ± s	right M ± s	left M ± s	right M ± s	left M ± s	right M ± s	left M ± s	right M ± s	left M ± s	left M ± s	left M ± s
30th	520 ± 10	[illegible] ± 11	—		433 ± 19	433 ± 19	—	—	138 ± 31	138 ± 31		—	[illegible]	—
31st	508 ± 13	[illegible] ± 24	−13 ± 21	3 ± 32	410 ± 8	410 ± 18	−23 ± 22	8 ± 6	113 ± 17	[illegible]	[illegible]	8 ± 33	133 ± 1[illegible]	−18 ± 13
32nd	488 ± 1[illegible]	[illegible]8 ± 17	−33 ± [illegible]2	[illegible] ± 21	40[illegible] ± 6	4[illegible]0 ± 14	−28 ± 22	18 ± 24	110 ± 22	[illegible] ± 22	−[illegible]8 ± 2	[illegible]	138 ± 17	−13 ± 10
33rd	488 ± 21	[illegible] ± 37	−33 ± 31	13 ± 12	398 ± 10	[illegible] ± 21	−3[illegible] ± 6	23 ± 33	100 ± [illegible]	[illegible]	−38 ± [illegible]6	0 ± 30	13[illegible] ± 19	−1[illegible] ± 11
34th	490 ± 24	[illegible] ± 37	−30 ± 30	[illegible]3 ± 13	403 ± 10	[illegible] ± 3[illegible]	−30 ± 21	38 ± 38	108 ± [illegible]	16[illegible] ± 17	30 ± 32	[illegible]	138 ± 11	−13 ± [illegible]

Table 19 B *Effect of Drilling of Corticalis on Normal Growth per Day (Group 1 and 4)*

Day after operation	Proximal tibia						Proximal fibula					
	right		left		left right		right		left		left right	
	μ	%	μ	%	μ	%	μ	%	μ	%	μ	%
1st	−[illegible]	−0[illegible]	10[illegible]	2 0	1[illegible]	2 9	−18*	−4 2	12[illegible]	2 8	30*	7 0
2nd	−21**	−4 2	16*	3 2	38***	7 4	−18*	−4 3	27**	6 4	[illegible]***	10 6
3rd	−13[illegible]	−2 [illegible]	33*	6 [illegible]	4[illegible]**	10	−21*	−[illegible]0	30***	8 7	[illegible]8***	13 7
4th	−9[illegible]	−1 9	43**	8 6	[illegible]3**	10 [illegible]	−1[illegible]	−3 7	[illegible]2***	12 4	[illegible]8***	16 1

Day after operation	Distal fibula						Distal radius	
	right		left		left right		left	
	μ	%	μ	%	μ	%	μ	%
1st	−2[illegible]*	−5 7	8[illegible]	1 7	33*	7 4	−13	−2 9
2nd	−2[illegible]**	−[illegible]7	18*	4 1	43 **	9 8	−14*	−3 0
3rd	−26*	−6 [illegible]	31**	7 3	8**	13 [illegible]	−1[illegible]	−3 3
4th	−17[illegible]	−4 0	40**	9 [illegible]	8**	13 [illegible]	−[illegible]	−1 3

Table 20 A *Growth per Day from Different Growth Plates in Group 5 (Periosteal Incision) in Series B*
Number of Animals 3

Day after birth	Proximal tibia (μ)				Proximal fibula (μ)				Distal fibula (μ)				Distal radius (μ)	
	Growth per day		Change in relation to that on 30th day		Growth per day		Change in relation to that on 30th day		Growth per day		Change in relation to that on 30th day		Growth per day	Change in relation to that on 30th day
	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	right M±s	left M±s	left M±s	left M±s
30th	540±10	543±6	—	—	450±10	450±10	—	—	453±6	453±6	—	—	457±2?	—
1st	507±2?	510±26	−33±23	−33±23	423±6	437±12	−27±6	−13±6	427±1?	443±21	−27±1?	−10±17	430±6	−27±1?
2nd	510±36	5?3±40	−30±40	−20±40	437±1?	457±23	−13±23	7±10	431±21	447±3?	−20±20	−7±31	433±21	−23±1?
3rd	517±2?	517±?	−23±31	3±2?	430±0	457±1?	−20±10	7±21	443±2?	457±39	−10±?0	3±32	410±26	−17±1?
4th	510±28	537±3?	−30±46	−7±35	427±15	453±1?	−23±11	3±2?	410±36	457±16	−13±31	3±10	410±30	−17±2?

Table 20 B *Effect of Periosteal Incision on Normal Growth per Day (Group 1 and 5)*

Day after operation	Proximal tibia						Proximal fibula					
	right		left		left right		right		left		left right	
	μ	%	μ	%	μ	%	μ	%	μ	%	μ	%
1st	−26***	−4 8	−26***	−4 8	0( )	0 0	−?2***	−?0	−9*	−2 0	13	3 0
2nd	−19( )	−3 6	−9( )	−1 7	10( )	1 9	−4( )	−0 9	16*	3 7	?0( )	?
3rd	−3( )	−0 6	23*	4 ?	2?( )	? 1	−6( )	−1 1	?1	4 7	2?*	6 1
4th	−9( )	−1 8	14( )	2 7	23( )	4 ?	−9( )	−2 0	17( )	4 1	2?( )	6 1

Day after operation	Distal fibula						Distal radius	
	right		left		left right		left	
	μ	%	μ	%	μ	%	μ	%
1st	−27***	−5 9	−10( )	−? ?	17*	3 7	−??**	−4 ?
2nd	−17*	−3 8	−4( )	−0 9	13( )	3 0	−4*	−? 3
rd	1( )	0 2	14( )	3 3	13( )	3 0	−1( )	−3 7
h	−1( )	−0 1	1?( )	? 7	1( )	3 8	−10( )	−? 2

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a survey of 57 cases

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END RESULTS IN THE TREATMENT OF SCOLIOSIS

A SURVEY OF 57 CASES

MUNKSGAARD
COPENHAGEN 1967

CONTENTS

INTRODUCTION

In most cases, a patient with progressive structural scoliosis needs surgical treatment in order to maintain the correction of the scoliotic deformity once it has been achieved All the main methods for correction of a scoliotic curvature in use to day are good e g the Milwaukee brace (3) the Risser localizer body cast (14) the Abbott molded body cast (1) the progressive elongation derotation and lateral flexion of the spine by Cotrel (6) but which of the operative techniques is the most likely to guarantee the permanency of the correction? This has been a difficult question since 1952 the year when Cobb presented his technique for spinal fusion (5) This question was also one of the main problems at the 10th congress of S I C O T in Paris in 1966 As has been stressed it is necessary to have a reliable assessment of the results of treatment in order to evaluate the usefulness of the actual methods *in casu* For an evaluation of the results of treatment sufficiently long periods of observations are imperative because a reliable evaluation of the results cannot be made before the completion of vertebral growth of the patient

An investigation into the treatment of scoliosis before 1962 at the Orthopaedic Hospital of The Invalid Foundation showed clearly that the results varied greatly depending on the different methods of spinal fusion (12 13) The scoliotic spine was corrected with the aid of a Milwaukee brace but in many cases the correction was lost after the operation The fusion was not rigid enough, the pseudarthrosis rate was high and was one of the important reasons for the failure to maintain the correction Here the quality of the bone grafts used for fusion proved to be of decisive importance Bone bank bone gave poorer results reported earlier from other countries (2 8) The results were more satisfactory with autogenous bone grafts but the results of treatment varied even with this depending on the different methods of handling the autogenous bone grafts Bone tissue is sensitive to several factors outside the organism such as soft tissues Its structure and vitality can easily be destroyed Therefore bone tissue must always be handled with great care In the use of bone tissue as transplantation material in orthopaedic procedures, the vitality of the bone grafts can at least be partly preserved provided that the bone grafts are transposed in a fresh condition *i e* that the transposition is done immediately This opinion is clearly confirmed by the experimental investigations on the technique of bone transplantation made by Puranen (11) As a result of these observations the following report seems justified

MATERIAL AND METHODS OF TREATMENT

Material

The data are based on the analysis of 57 patients with scoliosis (Table 1) operated on at the *Orthopaedic Hospital of The Invalid Foundation in Helsinki* during the period 1962—1964 Of these patients, 38 were girls and 19 boys

TABLE 1

CLASSIFICATION OF SCOLIOSIS

[illegible]	No. of Cases	Infantile Under [illegible] year	Juvenile [illegible] years	Adolescent Over 10 years	Cervicothoracic Curve	Main Thoracic Curve	Thoracolumbar Curve	Combined Thoracic and Lumbar Curve	Main Lumbar Curve
Idiopathic	26	1	4	21		23	3		
Paralytic	23				1	5	13	3	1
Miscellaneous*	8					4	3		1
Total	57				1	32	19	3	2

*Congenital anomaly 6 cases
Marfan's syndrome 1 case
After thoracotomy 1 case

Precorrection Curvature

Before treatment the 26 patients with idiopathic scoliosis had an average angle of curvature of 58 by Cobb measurement The 23 patients with paralytic scoliosis after poliomyelitis had an average curvature of 69 the 8 patients with congenital scoliosis 68 , the patient with Marfan's syndrome a curvature of 83 , and the patient with a thoracic scoliosis after an operation because of patent ductus arteriosus, a curvature of 62

Age at Time of Surgical Intervention

The average calendar age of the patients at the time of surgical intervention was 14 years and 11 months (Table 2) The skeletal age of the patients was determined by roentgenograms of the hands before treatment, after the operation and in connection with the follow up exam

inations The skeletal age was 1 to 2 years behind the calendar age in 26 patients at the beginning of the treatment in 2 cases the skeletal age was 1 year in advance, and for 29 patients the skeletal age corresponded to the calendar age

TABLE 2

AGE OF PATIENTS

Scoliosis	No. of cases	Average age at time of spinal fusion	Average age at completion of vertebral growth	Average age at last follow-up examination
Idiopathic	26	14 years 11 months	16 years 1 month	17 years 5 months
Paralytic	23	14 years 10 months	16 years 5 months	17 years 9 months
Congenital	8	15 years 5 months	16 years 11 months	17 years 10 months
Marfan s syndrome	1	15 years 7 months	17 years	17 years
After thoracotomy	1	14 years 2 months	16 years 3 months	16 years 3 months
Total	57	14 years 11 months	16 years 4 months	17 years 7 months

Age at Completion of Vertebral Growth

In connection with the roentgenographic surveys the capping of the iliac apophyses was noted With continued growth, the apophyses made contact with the ilium medially near the sacrum When this attachment or complete ossification has taken place, the vertebral growth was considered to be completed, according to the report of Risser (15) The average calendar age of the patients at the completion of vertebral growth (Table 2) was 16 years and 4 months, which is high in comparison with bone growths of patients in warm countries (15) The slow bone growth might influence the treatment by making it more difficult A patient with a long bone growth period seems to show a greater tendency towards a progression of the deformity The treatment should also be planned accordingly

Follow-up Time

The average calendar age of the patients at the last follow up examination was 17 years and 7 months (Table 2) Accordingly, the last follow up examination was undertaken 1 year and 3 months after the termination of the vertebral growth Thus the results presented here are end results and in this respect reliable

Correction of Scoliotic Deformity

Preoperative correction of the deformity was carried out in all cases by the Milwaukee brace in the making of which we have gained more experience thanks to Walter Blount who has visited our clinic several times and has shown us the correct way of making good braces The Milwaukee brace is not an extension apparatus of the trunk, even though the head support is kept high except during the first two weeks after the operation The patient can always raise his head from the support, exercising and strengthening the muscles of his back This active exercise in the brace generally together with two properly placed pads, corrects the scoliotic deformity of the spine The major pad was placed low enough Special attention was paid to the balance of the patient A good Milwaukee brace keep the body of the patient in balance In some cases protruding teeth were treated by an orthodontist, but there were generally no problems with dental protrusion

Fifteen patients were treated for more than 2 years with the Milwaukee brace before surgical intervention because of early onset of the deformity, five patients for one year eight patients for 3 to 8 months In 29 cases the preoperative treatment with the brace lasted only 1 to 2 months, which sufficed to familiarize the patient with the brace The brace was removed before the operation and reapplied on the day after the operation During the following two weeks, the brace was extended every day if possible and with this the final correction was achieved The treatment with the Milwaukee brace after spinal fusion continued for 9 months in 30 patients 10 months in 11 patients 11 months in 4 patients, 12 months in 4 patients, and for more than one year in 5 patients In 3 cases the treatment was continued for only 7 months

Operative Technique

Thirteen patients had a two stage procedure and one a three stage procedure On 43 patients the operation was performed in one stage



Fig 1 Approach



Fig 2 Decortication



Fig 3 Cortical grafts from tibia



Fig 4 Cortical grafts from tibia



Fig 5 Cancelous bone from tibial condyle



Fig 6 Bone grafts inserted

The average calendar age of the patients at the time of surgical intervention was 14 years and 11 months (Table 2)

The spinal fusion was carried out by 11 different surgeons using the Cobb modification and adding substantial amounts of autogenous tibial bone grafts into the fusion area In 10 cases the bone grafts were taken from the tibia two weeks prior to the spinal operation and stored in a bone bank In 17 instances, the tibial cortical grafts and spongious bone were taken first and placed in a bowl The leg wound was closed Only then was the scoliotic spine approached and the area to be fused prepared The grafts were then inserted

In 32 cases, the operation was carried out according to the method currently in use at the Orthopaedic Hospital of The Invalid Foundation To begin with, the scoliotic spine was exposed (Fig 1) and the area to be fused prepared with careful soft tissue excision and liberation, with a wide exposure of the curvature Spinous processes were cut down and cleaved Vertebral laminae and transverse processes were decorticated with a razor sharp hand gouge without using a mallet (Fig 2) The raised bone flaps were placed face down next to each other over the area to be fused, the transverse end attached The procedure was carried out on both sides Then three or four cortical grafts of suitable length and width were taken from the tibia (Figs 3 and 4) and enough cancellous bone from the tibial condyle (Fig 5) and inserted immediately, the cancellous bone under between and over the cortical grafts (Fig 6) The tibial cortical grafts should be both strong and long enough and extend over the entire curvature to be fused, mainly on the concave side Then the wound in the back was closed and finally the wound in the leg This order for covering the grafts as soon as possible was used in order to preserve the vitality of the bony tissue There were no complications or wound infections The correction of a fixed scoliotic curvature could after the operation be effected more easily because when preparing the area to be fused, tight ligaments on the concave side were discised The patient was kept recumbent for 4 months post operatively

RESULTS OF TREATMENT

The Cobb method of measurement of the scoliotic deformity was used The precorrection curvature was the maximum curvature before treatment with the patient standing, the corrected curvature was the minimum curvature after correction about 2 weeks postoperatively with the patient supine, and the final curvature was the curvature at the last follow up examination with the patient standing

The mean duration of the time from the operation to the last follow up examination was 2 years and 8 months The data were obtained from the author s personal observations at the follow up examinations of patients treated at this hospital Vertebral growth was complete in all patients at the time of the last follow up examination (Table 2)

Idiopathic, Paralytic, and Miscellaneous Cases of Scoliosis

The results of treatment are given in Tables 3—5 In 26 patients with idiopathic scoliosis, the average initial correction was 25 , or 46 per cent, with an average precorrection curvature of 58 The average final correction was 15 or 24 per cent and the average loss of correction 10 (Table 3) In 23 patients with paralytic scoliosis after polio, the average initial correction was 28 or 42 per cent, with an average precorrection curvature of 69 The average final correction was 11° or 15 per cent and the average loss of correction 17 In 6 cases with congenital scoliosis, the average initial correction was 28 , or 41 per cent with an average precorrection curvature of 68 The average final correction was 17 , or 25 per cent, and the average loss of correction 11 (Table 3) Pseudarthroses occurred in 11 out of 57 cases *i e* 19 per cent In the series before 1962 (13), the frequency of pseudarthroses was 29 per cent in 197 cases

Tables 4 and 5 give the results of treatment correlated with the different methods of transplanting autogenous bone grafts in spinal fusion in all 57 patients Direct grafting with fresh autogenous tibial bone seems to be superior to the two other types of grafting In only one case of direct bone grafting did pseudarthroses occur in the fusion area The frequency of pseudarthroses was surprisingly high in those patients in whom at operation the bone grafts were taken before surgical intervention on the spine and placed in a bowl, in readiness for later transplantation (Table 4) In an experimental investigation on the technique of bone transplantation, Puranen discusses the possible reason for the development of

pseudarthroses According to him, bone tissue in vital form cannot withstand exposure to air outside the organism, but after 1 or 2 hours behaves like bank bone, i e like dead tissue (11) The average loss of correction was only 9 in the 32 patients with direct bone grafting,

TABLE 3

CORRECTION OBTAINED FOLLOWING SURGERY

Scoliosis	No of cases	Average precorrection curvature	Average final correction		Average loss of correction	No of patients with pseudarthroses
		Degrees	Degrees	Per cent	Degrees	
Idiopathic	26	58	15	24	10	2
Paralytic	23	69	11	15	17	9
Congenital	6	68	17	25	11	
Marfan s syndrome	1	83	25	30	5	
After thoracotomy	1	62	19	26	8	
Total	57					11

TABLE 4

THE RESULT OF TREATMENT CORRELATED WITH THE TYPE OF BONE ADDED IDIOPATHIC PARALYTIC AND MISCELLANEOUS CASES OF SCOLIOSIS

Type of fusion and bone added	No of cases	Average precorrection curvature	Average Final correction		Average loss of Correction	No of patients with pseudarthrosis
		Degrees	Degree	Per cent	Degrees	
Cobb type fusion with banked autogenous tibial bone	10	72	13	18	17	3
Cobb type fusion with autogenous tibial bone kept in the open air 1—2 hours	15	69	9	13	18	7
Cobb type fusion with fresh autogenous tibial bone	32	58	16	27	9	1
Total	57					11

whereas the average loss of correction was 17 in 10 patients with banked autogenous bone grafts, and 18 in 15 patients with the bone grafts kept in a bowl for 1 to 2 hours before transplantation. It therefore seems reasonable to suppose that the freshly excised bone tissue was transplanted, at least partly, in a vital condition, an assumption which is also supported by Puranen's investigation (11).

The clinical result was good in 40 patients out of 57 with good improvement also demonstrable roentgenographically. With fresh, directly transplanted, bone grafts a good result of treatment was noted in 29 out of 32 cases (figs. 7 and 8). With bone grafts that had been stored in a bone bank for two weeks, a good result was obtained in half the cases only. When the bone grafts had been kept outside the organism in a bowl for 1 to 2 hours, good results were achieved in only 6 cases out of 15. The average loss of correction was only 8 in 29 patients with fresh bone grafts transplanted directly (Table 5). Taking into consideration the fact that the corrected curvature was measured with the patient supine and the final curvature with the patient standing, the loss of correction was slight.

TABLE 5

FORTY CASES WITH GOOD RESULT OF TREATMENT CORRELATED WITH THE TYPE OF BONE ADDED

IDIOPATHIC, PARALYTIC AND MISCELLANEOUS CASES OF SCOLIOSIS

Type of bone added	No. of cases with good result	Average final correction		Average loss of correction
		Degrees	Per cent	Degrees
Banked autogenous tibial bone	5 out of 10	19	28	11
Autogenous tibial bone kept in the open air 1—2 hours	6 out of 15	19	25	10
Fresh autogenous tibial bone	29 out of 32	17	29	8
Total	40 out of 57	18	28	9



Fig   Adolescent idiopathic scoliosis Girl aged 13 years 10 months at the time of Cobb type fusion with additional fresh autogenous tibial bone

Fig 8 The same girl 2 years after spinal fusion Initial correction 20 or 48 per cent final correction 17 or 40 per cent loss of correction 3

Causes of Loss of Correction in 17 Patients

In 9 cases, pseudarthroses in the fusion area were the reason for an average loss of correction of 20 In 5 patients, the spinal fusion was to short with an average loss of correction of 26 The reason for the loss of correction remained unknown in 3 cases with an average loss of 25

Idiopathic Scoliosis

The results of treatment are given in Table 6 The average loss of correction was only 8 in 18 patients fused with fresh autogenous bone grafts transplanted directly There were only 5 patients in the series with banked autogenous bone grafts with an average loss of correction of 16 , and 3 patients in the series with autogenous bone grafts kept in the open air for 1 to 2 hours before grafting with an average loss of correction of 13° and pseudarthroses in one case in each group No conclusion can be drawn, but fresh autografts seem to give a more solid fusion

TABLE 6

IDIOPATHIC SCOLIOSIS
THE RESULT OF TREATMENT CORRELATED WITH THE TYPE OF BONE ADDED

Type of fusion and of bone added	No. of cases	Average final correction		Average loss of correction	No. of patients with pseudarthroses
		Degrees	Per cent	Degrees	
Cobb type fusion with banked autogenous tibial bone	5	12	18	16	1
Cobb type fusion with autogenous tibial bone kept in the open air 1—2 hours	3	17	23	13	1
Cobb type fusion with fresh autogenous tibial bone	18	15	28	8	
Total	26	15	24	10	2



Fig 7 Adolescent idiopathic scoliosis Girl aged 13 years 10 months at the time of Cobb type fusion with additional fresh autogenous tibial bone



Fig 8 The same girl 2 years after spinal fusion Initial correction 20 or 48 per cent final correction 17 or 40 per cent loss of correction 3

DISCUSSION

According to the reports presented at the 10th Congress of S I C O T in Paris in 1966, concerning the end results in the treatment of idiopathic scoliosis, good results were achieved by different methods The results of treatment with Harrington instrumentation presented by Moe corresponded to the results with Risser localizer cast correction and spinal fusion presented in 1964 (9) The chief advantage of the Harrington instrumental correction seemed to be in earlier permissible ambulation, but more severe cases could be treated well with this method (10) Only time can show what happens to these instruments in the spine Cortrel corrected the scoliotic deformity with walking jackets moulded to the thorax, combining traction with derotation, in young children In cases of scoliosis towards the end of growth, he used progressive elongation of the spine The results were good (6) For spinal fusion he used two operative techniques, autogenous iliac bone grafts on a carefully prepared spinal bed or additional massive cortical heterografts, in the same way as Stagnara and Desbrosses (16) A good correction of the scoliotic deformity was achieved with the method of muscle alloplasty presented by Gruca (7), but the non surgical method of treatment of idiopathic scoliosis with the Milwaukee brace presented by Blount, also gave good results (4) Nevertheless, there are always cases with scoliosis in which one method might be the method of choice Therefore, all methods in use to day should be well known to everyone treating patients with scoliosis But this is hardly possible at present With a method giving good results in one surgeon's hands the results may be poor when it is used by another A poor result in the treatment of scoliosis is always disastrous This supports going on with one or two wellknown methods in the treatment of scoliosis The results will be good, even if not the best possible

In the present material, the method of choice was correction of the scoliotic deformity with the Milwaukee brace, and, in order to maintain the corrected position, the Cobb type spinal fusion with additional fresh autogenous tibial bone grafts The results were good in 29 cases out of 32, and the average loss of correction was only 8 (Table 5) The method is simple and easy to carry out by anyone treating patients with scoliosis surgically It should be mentioned that 6 different surgeons carried out the operation in these 29 cases Simplicity is one of the great advantages in this surgical method in the treatment of scoliosis

SUMMARY

The treatment of progressive structural scoliosis in the Orthopaedic Hospital of The Invalid Foundation in Helsinki is reviewed on the basis of 57 cases of spinal fusion. The patients were operated on during the period 1962—1964. Of these patients, 26 had idiopathic scoliosis, 23 paralytic scoliosis after polio, 6 had congenital anomalies in the spine, one suffered from Marfan's syndrome, and one had a scoliosis after an operation because of patent ductus arteriosus.

The average precorrection curvature was 58° in idiopathic scoliosis, 69 in paralytic scoliosis, and 68 in congenital scoliosis. The average calendar age of the patients at the time of spinal fusion was 14 years and 11 months, at the completion of vertebral growth 16 years and 4 months, and at the last follow up examination 17 years and 7 months. The mean duration of the time from the operation to the last follow up examination was 2 years and 8 months.

Preoperative correction of the deformity was carried out in all cases by the Milwaukee brace. In all cases, the spinal fusion was carried out by the Cobb modification by adding substantial amounts of autogenous bone grafts into the fusion area. In 10 cases the bone grafts were taken from the tibia two weeks prior to the spinal operation and stored in a bone bank. In 17 cases the tibial cortical grafts and spongious bone was taken before surgical intervention on the spine and placed in a bowl for 1 to 2 hours in readiness for later transplantation. In 32 cases, the operation was carried out according to the current method used at this hospital. To begin with the spinal bed was prepared. Then the tibial cortical grafts and cancellous bone from the condyle were taken and inserted immediately. No complications occurred.

In 26 patients with idiopathic scoliosis of 58°, the average initial correction was 25, or 46 per cent, the average final correction 15°, or 24 per cent and the average loss of correction 10°. In 23 patients with paralytic scoliosis of 69°, the average initial correction was 28°, or 42 per cent the average final correction 11°, or 15 per cent, and the average loss of correction 17. In 6 cases with congenital scoliosis of 68, the average initial correction was 28, or 41 per cent, the average final correction 17°, or 25 per cent and the average loss of correction 11°.

Direct grafting with fresh autogenous tibial bone seemed to be superior to the two other types of grafting. In only one cases out of 32 with direct bone grafting did pseudarthroses occur in the fusion area. The frequency of pseudarthroses was surprisingly high, in 7 out of 15 patients, when the

bone grafts were taken before surgical intervention on the spine and placed in a bowl in readiness for later transplantation With banked autogenous tibial bone grafts pseudarthroses occurred in 3 cases out of 10 Similarly, the average loss of correction was only 9 in 32 patients with direct bone grafting 17 in 10 patients with banked autogenous bone grafts, and 18 in 15 patients with the grafts kept in the open air for 1 to hours

The clinical result was good in 40 patients out of 57 with good improvement also demonstrable roetgenographically With fresh direct transplanted bone grafts a good result of treatment was noted in 2 of 32 cases the average final correction being 17 or 29 per cent and average loss of correction only 8 With bone grafts stored in a bone for two weeks a good result was gained in half the case only and grafts kept outside the organism in a bowl for 1 to 2 hours in cases out of 15

The methods of treatment of scoliosis in use to day are discu

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Some aspects of longitudinal bone growth

AN EXPERIMENTAL STUDY OF THE RABBIT TIBIA

ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM NO 103

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MUNKSGAARD COPENHAGEN 1967

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Introduction

For many decades the factors regulating the longitudinal bone growth have aroused interest Alimentary and hormonal factors that influence the organism as a whole have been studied in detail In orthopaedics the main interest has been to determine the underlying cause of a changed growth rate in individual skeletal parts These factors have been sought by experimentally *accelerating in different ways the longitudinal bone growth* However some problems are still unsolved and certain obscurities need clarifying in more detail Therefore the present work has been carried out *with the object*

of producing an accelerated longitudinal growth in a bone (rabbit tibia) with the aid of a method that is non traumatic as far as the bone is concerned

of analysing the factors involved in such a growth acceleration

of studying at this accelerated growth the intra osseous blood flow

Chapter 1 Accelerated bone growth

I Earlier investigations

The possibility of influencing the longitudinal bone growth was investigated as early as 1867 by Ollier who observed the occurrence of this after periosteal stripping of the tibia in the growing rabbit. Since then a series of growth stimulating methods have been tested experimentally. The experiences thus gained have been applied clinically. At various diseased conditions a locally more rapid skeletal growth has also been noted.

A survey of the literature reveals one group of growth stimulating methods that involves direct traumatization of the investigated skeletal part whereas another group leaves the bone intact, its effect being indirect.

A STIMULATION OF LONGITUDINAL BONE GROWTH BY DIRECT MEASURES

1 Röntgen

The effect of ionizing radiation on the growing skeleton has been the object of several investigations. Baunach (1935) showed experimentally on rabbit that a low röntgen dose produced an initial and brief growth stimulation as an expression of an irritative effect. Larger doses were followed by growth retardation, the younger the experimental animal the more pronounced the effect. This accords well with the findings of other investigators (*inter al.* Langenskiöld & Edgren 1949). Of more recent works can be mentioned that of Phillips & Kimeldorf (1966) who studied in detail the retardation of skeletal growth in rat taking into account dosage and age of the animal.

2 Heat

Richards & Stofer (1959) reported stimulated longitudinal bone growth in experimental animals after increasing the skeletal temperature by the application of an electrically heated wire. A positive effect produced by increased heat was also obtained by Doyle & Smart (1963) who used moderate doses of short wave diathermy. Wilson & Thomson earlier

(1939) used that method on a small group of patients suffering from unilateral paralytic growth retardation of the lower extremity. There was usually no further increase in the existing length discrepancy after the treatment. A slight growth stimulation was also noted clinically by BERTRAND & TRILLAT (1948).

According to WISE *et al.* (1949) the application of heat results in growth retardation in young rats. The amount of heat they mention, however, has been considered too large (DOYLE & SMART 1963, GRANBERRY & JANES 1963). The latter gave a moderate application to growing dogs, but failed to record any significant effect on longitudinal growth, nor could DE FOREST *et al.* (1953) do so with ultrasound, or RING & LEE (1958) with a carbon resistor in the distal ulnar epiphysis in rabbit. RING (1961) observed no effect from increased heat on the sequelae of poliomyelitis in children.

3. Trauma to the medullary cavity

KISHIKAWA (1936) noted that drilling into the tibial diaphysis in rabbit produced an increase in the longitudinal growth of the bone. HUTCHISON & BURDEAUX (1954) obtained some effect after drilling into the femoral metaphysis in dog.

FERGUSON (1933) obtained growth stimulation after drilling and curettage of the bone marrow in the tibial and fibular diaphysis in children.

Both COMPERE & ADAMS (1937) and WU & MILTNER (1937), on the other hand, failed experimentally to record any effect. HANSSON & WIBERG (1963) reported only insignificant increase in length after drilling in the tibial metaphysis of rabbit.

4. Application of various materials in the medullary cavity

Since VON LANGENBECK'S (1869) positive experiment of inserting an ivory plug into the medullary cavity in experimental animals, a large number of experimental works have been carried out where, by the irritation of a foreign body in the vicinity of the growth plate, an accelerated growth has been attempted. (In some instances, two different metals have been implanted with the object of using also the electrolytical effect.) A great variety of materials have been used. MEISENBACH (1910), KONIOSWIESER (1925), BERGMANN (1931), KISHIKAWA (1936), WILSON & PERCY (1956) are among those who by this type of operation could observe a growth stimulation. This was also observed by TRUETA (1953, 1958) with a somewhat modified method involving extensive destruction of the medullary cavity, which is then filled with foreign material.

Many investigators *inter al* TROUT (1915) BOHLMAN (1929) WU & MILTNER (1937), CHAPCHAL & ZELDENRUST (1948) HERNDON & SPENCER (1953) HAAS (1958) either recorded no effect or observed a retardation in the longitudinal bone growth after implantation of foreign materials

In several of the mentioned experiments infectious material was used It is an old clinical experience that a limb with a local inflammation often shows signs of stimulated skeletal growth (LANGENBECK 1869 BERGMANN 1931 WILSON & MCKEEVER 1936 TRUETA 1953)

The experimental knowledge was used in 1952 by PEASE who in 7 children with anisomelia applied different metals or ivory into the metaphyses at the knee joint he noted growth stimulation in all patients Effects of similar operations have also been reported by *inter al* CARPENTER & DALTON (1956 1963) and NORDENTOFT & GULDHAMMER (1964) but they emphasize that the gain obtained in longitudinal bone growth is so slight that in most instances it does not justify the operation WILSON & PERCY (1956) could detect no effect whatever from this procedure

5 Periosteal stripping

OLLIER (1867) loosened most of the periosteum from the diaphysis in growing rabbit tibia and three months later observed an increase in length of 2—5 mm Several investigators (WU & MILTNER 1937 LACROIX 1947 BERTRAND & TRILLAT 1948 BRODIN 1955 ELO 1960 and SOLA *et al* 1963) later using the same method noted a significant increase in the longitudinal bone growth BRODIN was the first to show in more detail that periosteal stripping from the proximal rabbit tibia is followed by decreased activity of the proximal growth plate and increased of the distal The latter effect predominates therefore the net result is a slight increase in the growth rate of the tibia as a whole

A modified method has been tried by placing foreign matter or organic tissue between the periosteum and the cortex (LANGENSKIOLD 1957 ELO 1960) but SOLA *et al* (1963) consider this method to be inferior to stripping alone

A second stripping procedure does not appear to increase the stimulating effect (SOLA *et al* 1963) and if the periosteum as well as the perichondrium is removed growth retardation occurs (HAAS 1917 SOUSA PEREIRA 1938 ELO 1960)

The clinical value of the method has been appraised by *inter al* BERTRAND & TRILLAT (1948) ZANOLI (1949) PEASE (1952) TAILLARD (1959) and SOLA *et al* (1963) Periosteal stripping in children suffering from growth retardation of a lower extremity thus produces a moderate growth stimulation

6 Fracture

Experimental diaphyseal fractures (Bisgard 1936 Compere & Adams 1937, Greville & Janes 1957) are followed by stimulated growth of the fractured bone Both Bisgard (1936) and Compere & Adams (1937) think that the stimulation is local in character and does not refer to the other bones in the extremity involved This is contradicted by Wray & Goodman (1961) who found that a fracture through the tibial diaphysis in rat causes during the immediately following period growth retardation of the femur both in the fractured and the non fractured extremity A period then ensues when both femurs show increased growth but where the growth of the femur of the fractured extremity is significantly greater than that of the corresponding bone on the contralateral side Earlier Levander (1929) after fracturing the tibial diaphysis in rabbit observed a temporarily increased growth of the femur in the same extremity

Several investigators have noted that diaphyseal fractures in children are often followed by an increased longitudinal growth of the fractured bone (Truesdell 1921 Burdick & Siris 1923 Cole 1925, Levander 1929, Bisgard 1936 Aitken *et al* 1939 Hedberg 1945 Bertrand & Trillat 1948, Trueta 1953 Edmneus & Wiberg 1958 Guldhammer 1963 *inter al*) Sometimes an increased growth originates also in other bones in the extremity (Cole 1925 Bertrand & Trillat 1948 Goff 1960)

The general opinion is that the accelerated growth after fracture is not due to an increased amount of bone tissue at the place of the fracture but is a result of increased metaphysial activity Bisgard (1936) illustrated this in his experiments and Wray & Goodman (1961), besides Cole (1925) and Levander (1929) have also shown that the stimulus was not solely localized to the fractured bone

In the above survey investigations of experimental or clinical nature where two or more methods were combined to obtain growth stimulation, have been omitted

The causal relationship

The following theories have been suggested concerning the mechanism underlying the growth stimulating methods reported above

Rontgen The growth increase observed here has been interpreted as an expression of an irritative effect due to the ionizing radiation

Heat By increasing the temperature in the tissues heat has been thought to produce a diffuse hyperaemia or in some cases a more local one Richards

& STOFER (1959) describe both an arterial and a venous hyperaemia which they found in injection studies and which they then thought stimulated the growth plate

Trauma to the medullary cavity as well as the *application of various materials* into it produces a greater or lesser damage to intra-osseous vessels The growth stimulating *effect according to* FERGUSON *(1933) is to be found* in interruption of the metaphysial blood flow HUTCHISON & BURDEAUX (1954) look for the explanation in the venous stasis that occurs TRUETA (1953) and CARPENTER & DALTON (1956) think that by blocking periosteal and diaphysial vessels the arterial blood is forced to a greater extent than usual through the metaphysial vessel channels resulting in a stimulation of the longitudinal bone growth HANSSON & WIBERG (1963) however call attention to the hyperaemia that accompanies a healing process and that by way of the metaphysial vessels can act as a stimulus

Application of various materials into the medullary cavity also includes the introduction of what is usually a foreign body and sometimes of infectious material This creates a condition of irritation with varying degrees of necrosis that induces a hyperaemia The hyperaemia acts also on the growth plate and stimulates longitudinal bone growth (LANGENBECK 1869 KONIGSWIESER 1925 KISHIKAWA 1936 CHARCHAL & ZELDENRUST 1948 PEASE 1952)

It is the irritation element at periosteal stripping that acts as a stimulus according to earlier investigators (*inter al* OLLIER 1867) LACROIX (1947) thinks that the procedure has a direct effect upon the growth plate by liberating a growth stimulating substance most investigators however consider that the changed rate of growth is due to disturbed circulation caused by the damages to the periosteal osseous vascular connexions (SOUSA PEREIRA 1938 BRODIN 1955) The effect according to TAILLARD (1959) is a *growth stimulating hyperaemia in the bone most pronounced in the epiphysial region* (SOLA *et al* 1963) The latter suppose that the operation through damage to the vascular connexions to the diaphysis increases the blood flow in the vessels between periosteum and epiphysis ZUCMAN (1960) by means of an injection method showed that a loosening of the periosteum was followed by an extensive dilatation of the periosteal vessels earlier BRODIN (1955) with the aid of isotope labelled erythrocytes and a fluorescence method thought he could detect an increased blood flow to the epiphysial metaphysial regions

The mechanism underlying the growth stimulation at *fracture* of long bones is generally thought to lie on the vascular plane Some authors believe that

the fracture causes *inter alia* irritation of the periosteum resulting in an increased blood flow which can effect and thereby stimulate the growth plate (LEVANDER 1929, BISGARD 1936, BERTRAND & TRILLAT 1948). HEDBERG (1945) considers the hyperaemia to be related to the degree of the callus formation, whereas TRUETA (1953) thinks that the essential is a blocking of the medullary vascular channels with an activation of the periosteal circulation (CAVADIAS & TRUETA 1965) whereby the blood is, to an increased extent, forced into metaphysial vessels.

WRAY & SPENCER (1960) could establish a pronounced increase of the arterial inflow in the limb after fracture of a long bone in dog, but because a stimulated longitudinal bone growth could also be noted on the contralateral side, a generally acting factor, possibly an increased liberation of growth hormone, could be important here (WRAY & GOODMAN 1961).

B. STIMULATION OF LONGITUDINAL BONE GROWTH BY *INDIRECT MEASURES*

1. Disturbed innervation

As is well known, a disturbed innervation in a growing person can be reflected in the structure and development of the skeleton, including a disturbed longitudinal bone growth.

Many investigations have been made into the skeletal innervation, and nerve ends have been found in compact bone as well as in bone marrow. (SHERMAN 1963 surveys the earlier literature.)

CURCIO (1898) stated that he had experimental evidence that a trophic centre of the skeleton was situated in the spinal cord. Many of his contemporaries had the same belief about the tropism relationship between the nervous system and the skeleton. (For review, see CASSIRER 1912.)

The trophic relationship was later adopted by HURRELL (1938), who observed in cat unmyelinated nerve endings in the matrix next to the bone cells. He thought that they may be the sensory and effector endings required for a reflex control of bone growth and maintenance.

MILLER & KASAHARA's (1963) work can be mentioned among more recent investigations. They applied methylene blue immersion technique and investigated long bones from *homo*, rabbit and rat. No principal species difference was found. Numerous myelinated and unmyelinated nerve fibres pass through the nutritional foramen and ramify in the bone marrow and endosteum in the diaphysis. Similar thin nerve fibres pass through the cortex by way of the many foramina found in the epiphysial-metaphysial region. Myelinated nerve fibres can be seen winding around bone trabeculae and ramifying under the inner surface of the joint cartilage. The

authors think that these fibres are sensory and can have something to do with the positional sense Unmyelinated nerve fibres are found mostly around vascular structures These have also been noted by SHERMAN (1963) who presumes that they belong to the autonomic nervous system and are concerned with the regulation of the blood flow Little evidence supports the idea that the skeletal bones get fibres from anterior horn cells of the spinal cord (GILLESPIE 1954)

The large number of experimental works that exist concerning the effect of denervation upon bone growth can probably be related to the marked changes recorded clinically *in the growing skeleton at injuries of the nervous* system and the thereby connected therapeutic problems that arise at for instance the treatment of the sequelae of poliomyelitis

The results of experiments must be judged against the background of how the denervation is carried out TROUPP (1961) has partly touched on this Anatomically the same result of nerve root sectioning as of peripheral nerve sectioning cannot be expected Sectioning of the posterior root thus produces a sensory denervation Sectioning of the anterior root besides motor denervation injures preganglionic sympathetic nerve fibres—if the root involved lies cranially to the lowest level of the preganglionic outflow to the sympathetic trunk—and also causes an interruption to a number of postganglionic sympathetic fibres as shown in recent investigations by DAHLSTROM & FUXE (1965) They demonstrated that noradrenalin-containing nerve fibres of supraspinal origin leave the spinal cord through the anterior roots and bypass the ganglion cells of the sympathetic trunk without synaptic contact Finally the result of peripheral nerve sectioning is an interruption of sensory motor and postganglionic sympathetic nerve fibres

Sensory nerve injury

GREY & CARR (1915) and GILLESPIE (1954) failed to affect the bone growth by cutting sensory roots (GREY & CARR however say nothing about the age of the experimental animals) RING (1961) also failed with peripheral sensory denervation (section of the sural nerve in rabbit) TROUPP (1961) however observed after sectioning posterior roots in rabbit that the femur on the denervated side showed marked growth retardation but the tibia did not The same experiment was repeated with the denervated extremity protected by the abdominal skin The growth retardation of the femur was then considerably less and in some cases the longitudinal growth of the tibia was accelerated

Motor nerve injury

GREY & CARR in 1915 made a selective denervation by sectioning anterior roots GILLESPIE (1954) did the same experiment in young cats However

these investigators could observe no effect upon the longitudinal bone growth According to TROUPP (1961) various degrees of anterior root lesions in rabbit causes growth retardation of the denervated bones in relation to the extent of the denervation Sectioning anterior roots in young dogs resulted in a significant increase in longitudinal growth of the tibial diaphysis *on the denervated side* (RING 1961) *but the author could observe* no effect from the same operation in kittens

Injury of sympathetic nervous system pharmacological sympathetic blockade

The effect of sympathectomy on the longitudinal bone growth was studied by *inter al* KISHIKAWA (1936) who obtained moderate growth stimulation in the lower extremity after lumbar sympathectomy in puppy GULLICKSON *et al* (1951) achieved the same result in a similar experimental animal they noted also a growth retardation after prolonged stimulation of the lumbar sympathetic trunk GOETZ *et al* (1955) sympathectomized young rabbits and observed increased growth of the foot skeleton

Most experimental works, however, present no evidence that sympathectomy stimulates growth (CANNON *et al* 1929 BACQ 1930 BERGMANN 1931 BISCARD 1931, HARRIS & MCDONALD 1936 RING 1961, TROUPP 1961)

HARRIS & MCDONALD (1936) reported four patients with Hirschsprung s disease, all underwent unilateral lumbar sympathectomy The lower extremity on the same side in all patients was longer than that on the other side FAHEY (1936) studied two similar cases but found no signs of stimulated skeletal growth The lumbar sympathectomy and the pharmacological sympathetic blockade lessen the growth retardation after poliomyelitis, according to HARRIS & MCDONALD (1936) BARR *et al* (1950) KOTTKE *et al* (1958) whereas WHITE (1931) NORDENTOFT & GUIDHAMMER (1964) could not positively observe this favourable effect STEWART (1937) *studied the effect of the operation on bone growth in children with cerebral* paresis but noted only minor results

Peripheral nerve injury

Many experimental works concern the effect upon bone growth of peripheral nerve sectioning MILNE EDWARDS (1860) cut off the mandibular nerve and thereby produced hypertrophy of the mandible OLLIER (1867) is the first to mention atrophic elongation He noted several times in experimental animals how a denervated bone had diminished in width but had increased in length NASSE (1880) and GHILLINI (1897) made similar observations RING (1961) showed that peripheral nerve sectioning in rabbit produces a significant increase in the length of the tibial diaphysis

Several investigators *inter al* BOREL (1922), BERGMANN (1931) SELYE & BAJUSZ (1958) HERT (1959), are of the opinion that peripheral nerve sectioning has no effect whatsoever on the longitudinal bone growth Others (HOWELL 1917 ALLISON & BROOKS 1921 ARMSTRONG 1946 GILLESPIE 1954 *inter al*) however noted bone atrophy with varying degrees of growth retardation

Growth retardation has been found clinically after peripheral nerve injury in children (VON LANGENBECK 1869 FISCHER 1871 COMBES *et al* 1960 *inter al*)

Poliomyelitis

The sequelae of paralytic poliomyelitis have been studied in detail and important findings have here been made concerning the influence of the nervous system upon the growing skeleton Some disagreement exists about whether the condition, apart from the damage to the anterior horn cells and to sensory structures (MOLDAVER 1944) also results in injury to the sympathetic innervation Most investigators (*inter al* COLLINS *et al* 1947 SMITH *et al* 1949 STENPORT 1951 MCPHERSON & KESSEL 1955 GOETZ *et al* 1955 HAGELSTAM 1956 KOTTKE *et al* 1958 FANCONI 1959 SPENCER *et al* 1960) believe that the autonomous nervous system is always affected at poliomyelitis GOETZ *et al* (1955) emphasize that poliomyelitis is a disease of the gray matter and that there is no reason why cells responsible for the preganglionic sympathetic outflow should be exclusively spared indeed lesions have been found in those cells (SABIN 1942 MOLDAVER 1944) HORANYI HECHST (1935) however found them to be completely intact in most cases SHARRARD (1959) asserts that those cells in particular are capable of resisting poliomyelitis virus and are affected only at very extensive damages RING (1961) thinks that no permanent damage of the sympathetic nervous system occurs whereas TELFORD & STOPFORD (1933) GASK & ROSS (1937) and TROTT *et al* (1958) find no signs whatever that the autonomous system is affected at poliomyelitis

The effect of poliomyelitis on the longitudinal bone growth has been discussed exhaustively SEELIGMULLER (1879) was able to note an initial growth acceleration in a paretic extremity This is rather the rule during the first year of the disease (GREEN & ANDERSON 1955) This phenomenon was also observed by LERIQUE (1956) and RATLIFF (1959) RING & WARD (1958) found that the immediate effect of the nerve injury at poliomyelitis is an increased longitudinal growth of the affected bones This occurs during the first year of the disease and can also remain during the second year Thereafter the longitudinal growth of the paralysed limb is retarded, and the length discrepancy will increase throughout the entire remaining growth period with a shorter paretic extremity as the net result

The retarding effect of the disease on the skeletal growth has been investigated by many, *inter al.* HUMPHRY (1862), STINCHFIELD *et al.* (1949), GULLICKSON *et al.* (1950), GREEN & ANDERSON (1955), RING (1957, 1958 a), RING & WARD (1958), RATLIFF (1959), LINDHOLM (1961).

The causal relationship

The analysis of experimental works as well as of clinical observations concerning innervation and skeletal growth is complicated in so far as many factors must in this connexion be considered, namely sensory, somato-motor, and autonomous. This has not always been taken into account. The changes observable regarding the longitudinal bone growth after *sensory denervation* has been interpreted as secondary to the increased traumatization resulting from reduced sensibility (RING 1961, TROUPP 1961).

Sectioning of anterior root, injury to peripheral nerve, or *affection by* poliomyelitis virus in all instances result in, *inter alia*, interference with *the motor innervation*. According to SEELIGMÜLLER (1879) disturbance of the trophic relationship is also included; this could lie behind a growth acceleration. LANGENBECK (1869) and FANCONI (1959), however, would like in that way to explain a decreased growth activity.

Many investigators have called attention to the stresses and strains that the long bones in a normally functioning extremity are subjected to. Thus OLLIER (1867) seeks the explanation of the atrophic elongation in the decreased pressure and muscle tension, an opinion that was later shared by, *inter al.* SEELIGMÜLLER (1879), NASSE (1880), GHILLINI (1897). RING & WARD (1958) and RING (1961) interpret a reduced or abolished pressure and tension on the skeleton as at least one contributory cause of such an elongation.

Mechanical factors in the form of normal stress and strain are regarded as essential for normal skeletal growth, and a change in these has been considered as contributing cause of the growth retardation observed after motor nerve damage (HARRIS & MCDONALD 1936, GULLICKSON *et al.* 1950, PEASE 1952).

Several authors (*inter al.* STINCHFIELD *et al.* 1949, GULLICKSON *et al.* 1950, RING 1957, 1961) *treat particularly the relation between the extent* of growth retardation and the degree of paresis from the standpoint of changed conditions in pressure and tension. (See further the section on mechanical factors.)

A motor denervation produces marked changes in the circulation in an extremity, and the relation between muscle activity and skeletal blood flow has been emphasized (OLLIER 1867, BLAIR 1938, MORGAN 1959). In this respect bone and cartilage with surrounding musculature are regarded

as one functional unit (GEISER 1957 BROOKES 1958, RING 1961 TRUETA 1961 1964) The bone elongation at polio in accordance with this has been ascribed to a shunting of blood from the muscles to the skeleton (FANCONI 1959 TROUPP 1961), the skeleton getting a relatively larger share of the extremity s blood supply because of the reduced metabolic demand by the paretic musculature (RING & WARD 1958 RING 1961) On the *other hand a reduced circulation secondary to defective muscle activity in* a paretic extremity has been indicated as the chief cause of the observed growth retardation (HARRIS & McDONALD 1936 GULLICKSON *et al* 1950 PEASE 1952 RING 1957 1961) TELFORD & STOPFORD (1933) maintain that the primary factor here is a reduced venous backflow to which GASK & ROSS (1937) ascribe the greatest importance others however lay greater emphasis on the reduced arterial inflow (GULLICKSON *et al* 1950 PEASE 1952 RING 1957 1961) A disuse of an extremity since childhood caused by an innervation disorder can reveal itself as an organic change in the vascular system in the form of an arterial infantilism (GOETZ *et al* 1955 McPHERSON & KESSEL 1955) (The relation between muscle activity and blood circulation are further discussed in the section on immobilization)

As mentioned sectioning of motor roots as well as peripheral nerves results in injury to the *symphathethic nervous system* many consider this to be the case at poliomyelitis too The changes in the bone growth demonstrated in these instances or after sympathectomy have been thought to be due to changed vasomotion and thereby changed blood circulation

The accelerated skeletal growth that could be established experimentally and clinically after sympathectomy is explained by a reduced vasoconstriction resulting in increased blood flow and thus stimulation of the growth plates (KISHIKAWA 1936 HARRIS & McDONALD 1936 GULLICKSON *et al* 1951 GOETZ *et al* 1955) Measurements of blood flow indicate (HERRICK *et al* 1932 THEIS 1933 COLLINS *et al* 1947 DETERLING & ESSEX 1949 SAKO *et al* 1959 FOLSE 1965) an increase of the total flow of a limb but it has been questioned (WILKINS & EICHNA 1941 STEIN *et al* 1948) whether this increase is wholly or partly to be referred to the skin PAPPENHEIMER & MAES (1942) state that the flow increase concerns the musculature too this is also reported by LAMBERT (1957 1960) SCHONBACH (1964) and VAN DE BERG *et al* (1964)

FELL described in 1949 how injury to the sympathetic innervation can produce hyperaemia in the skeleton LOWENSTEIN *et al* (1958) as well as TROTMAN & KELLY (1963) point to an increased blood flow in dog tibia after lumbar sympathectomy Bone clearance of radiostrontium (SHIM *et al* 1966) indicates a significantly increased blood flow in talus and calcaneus

in rabbit 1 to 2 weeks after sectioning the sciatic nerve The author attributes the change entirely to interruption of the sympathetic nerve supply of the bone Analogous to this DRINKER & DRINKER (1916), PETRAKIS (1954) HERZIG & ROOT (1959), WEISS & ROOT (1959), CUMMING (1962), AZUMA (1964) SHIM (1966) also interpret their findings as a reduction of the intra osseous blood flow after sympathetic stimulation or administration of sympathomimetics

The mentioned results are contradicted by the slight or completely absent stimulation of the skeletal growth as reported in other experimental and clinical works Many investigations both symptomatologic (PALOSCHI & LYNN 1964) and those concerning the haemodynamic after sympathectomy are in total agreement with this SHAW *et al* (1964) give an account of a 10 year material of sympathectomies and find so slight an increase in muscle circulation that it can be considered of no practical significance, especially as no change after exercise could be detected BEACONSFIELD (1954) and MYERS & IRVINE (1966) report similar results BARCROFT & SWAN (1953) could, it is true by plethysmography measure initially in *homo* an increased muscle blood flow after sympathectomy but a return to normal level occurred after a few hours or days LAMBERT (1957 1960) and SCHONBACH (1964) *emphasized also the short duration of the circulation increase experimentally* SCHONBACH shows also that the vascular tonus post sympathectomiam after a varying time not only returns to the original level but even takes a position above the normal

The return of tonus in the sympathectomized vessels according to MONRO (1959) *can best be explained by reorganization of preganglionic fibres by* collateral sprouting whereby functional connexion with intact ganglion cells is established

Another explanation has been sought in sensibilization of the vascular musculature of a circulating vaso constrictor substance (*inter al* LECOMPTE 1941) This effect has later proved to be due to circulating noradrenalin (MACMILLAN *et al* 1962)

The angiographic picture is quite unchanged after sympathectomy in rabbit (HULTH & OLERUD 1960) CUTHBERTSON *et al* (1964 a) VALDERRAMA & TRUETA (1965) and SHAW (1965), who recorded blood flow change with the aid of intra osseous pressure measurement could find no signs of autonomous influence on the skeletal blood vessels

Finally it should also be mentioned that ZINN & GRIFFITH (1941) refer to reduced flow (dye injection) *in rat tibia after sympathectomy* thus they interpret as a result of a relatively larger dilatation of the soft tissue vessels BRAUNSTEINER & GRABNER (1958) at flow measurements in the sternal medulla in *homo* (thermocouple) found that sympathomimetics produced an increase of the blood flow

It has been postulated that an important factor in the origin of muscle atrophy is a disturbance of the autonomous nervous system which secondarily can be thought to affect the skeletal growth Among recent works referring to this problem can be mentioned that of HELANDER (1960) He showed in rabbit that a sympathectomy does not affect the histological picture of the skeletal muscle he emphasizes at the same time however that the sympathetic tone in rabbit is weak and that the results are therefore *not with certainty reproducible in other species*

Concerning poliomyelitis several authors (see above) have referred to—besides other nervous disfunctions—a simultaneous injury to the sympathetic nervous system the retarded longitudinal bone growth a result of reduced circulation has to a varying extent been attributed to a disturbed sympathetic innervation (OGILVIE 1932 GULLICKSON *et al* 1950 GOETZ *et al* 1955 RING 1957 KOTTKE *et al* 1958) This also manifests itself in other vascular phenomena such as coldness cyanosis swelling clamminess of the involved limb the explanation has been sought in an abnormal reaction to cold in the form of pronounced angiospasm (TELFORD & STOPFORD 1933 HARRIS & McDONALD 1936 COLLINS *et al* 1947 SMITH *et al* 1949 STEVPORT 1951 KOTTKE & STILLWELL 1951) The disease is believed to destroy internuncial neurons situated close to the sympathetic neurons in *the intermediolateral column and normally inhibiting these neurons* The result of the reduced or lost inhibition is hyperactive responses to afferent stimuli among which is cold This changed sympathetic activity concerns in the main the vessels in the skin (WILKINS & EICHNA 1941) others (TROTT *et al* 1958 KOTTKE *et al* 1958) state that also deeper lying vascular structures are similarly affected Thereby the blood flow to the skeleton is also influenced resulting in a disturbed longitudinal bone growth A pharmacological sympathetic blockade increases the blood flow measured at the ankle (COLLINS *et al* 1947) and can to some extent reduce a growth retardation (KOTTKE *et al* 1958)

2 Disturbed circulation

By eliminating to a varying extent the arterial flow to a long bone it was possible to observe experimentally different degrees of avascular necrosis delayed healing of fractures and reduced growth potential (For literature survey see TROUPP 1961, TRUETA & CAVADIAS 1964) A growth stimulation has in some cases been obtained It has then been a question of direct traumata to the vascular system as a result of an operation of the type earlier reported (drilling stripping etc)

Increase of arterial flow

Experimental attempts to increase the arterial flow to a long bone by direct surgical diversion of an arterial channel into bone have been made in recent years (WOODHOUSE 1963 DICKERSON & DUTHIE 1963, BOYD & AULT 1965, DICKERSON 1966) The artery with maintained blood flow, has been implanted under conditions as physiological as possible Long term experiments were involved, the acute traumatizing effect could therefore be eliminated When the method was applied to growing animals an obvious increase of the growth in length was obtained compared with the control side and with a group of sham operated animals (DICKERSON 1966)

Arterio venous fistula

More than a century ago BROCA (1856) *inter al* noted an accelerated growth of both femur and tibia in a child with an arterio venous aneurysm situated immediately distal to the inguinal ligament Several similar reports have since been published FRANZ (1905), HORTON (1932), HARRIS & McDONALD (1936), BIRNSTINGL (1962) *inter al* These clinical observations were followed by a number of experimental works JANES & MUSGROVE (1950) KELLY *et al* (1959) DOERR & JANES (1959) VANDERHOEFT *et al* (1963) KECK & KELLY (1965) created in puppies iliac or femoral arterio-venous fistulas and observed an increased growth in length of the bones in the lower extremity

The method was introduced clinically in 1952 by JANES & ELKINS and has been applied to children with length discrepancies in the lower extremities resulting in growth acceleration (HIERTONN 1957, 1961, COOLEY *et al* 1960 JANES & JENNINGS 1961)

Venous stasis

One interpretation of the reason for the increased growth in length at an arterio-venous fistula is venous stasis Obstructing the venous return has been attempted with the object of accelerating the bone growth BIER (1906) mentions in his monography Hyperaemie als Heilmittel that a venous stasis of an extremity is reflected deep into the medullary cavities of the bones and frequently gives rise to an increase both in length and in thickness of the bones Experimental venous ligatures in the lower extremity in young rabbit resulted in an increased longitudinal growth of the skeletal parts involved (BOREL 1922) The experiment was later reproduced by BERGMANN (1931) KISHIKAWA (1936) SERVELLE (1948) HUTCHISON & BURDEAUX (1954) put tourniquets on the legs of puppies and obtained increased longitudinal bone growth PEARSE & MORTON (1930) observed accelerated fracture healing at simultaneously created venous stasis COLT &

IGER (1963) experimented on young dogs by stenosing in varying degrees the femoral vein Both femur and tibia showed accelerated growth of mod erate and in some instances minimum extent

However the literature gives examples also of experiments where the venous stasis was ineffectual (GREY & CARR 1915 DICKINSON 1953 KECK & KELLY 1965)

HELFERICH (1887) described several instances of one shorter lower ex tremity in children where a venous stasis produced externally resulted in an increased longitudinal growth in length SCHULLER (1889) obtained a similar effect in two children with poliomyelitis The pure venous stasis has been very little used as therapeutic aid during the present century

Clinical conditions including extensive varicose changes in the lower extremities since childhood however have been reported often with marked increased skeletal growth in the limb concerned Sometimes a simultaneous occurrence of haemangioma in the skin has completed the triad that composes Klippel Trenaunay s syndrome (KLIPPEL & TRENAU NAY 1900 BOREL 1922 SERVELLE 1948 FOSTER & KIRTLEY 1959)

The causal relationship

The accelerated skeletal growth after the *implantation of artery* in a long bone of a growing animal has been explained by the stimulating effect an increased arterial blood flow exerts upon a growth plate It has thus been possible already after three weeks to observe a rich amount of anastomoses between the implanted vessel and the intra-osseous arterial system (WOOD HOUSE 1963)

An increased arterial flow to the skeleton has been mentioned as back ground to the growth stimulation at an *arterio venous fistula* (JANES & MUSGROVE 1950 DOERR & JANES 1959 HIERTONN 1961) sometimes in the form of an arterial backflow in the veins (HOLMAN 1955) The venous stasis is a contributing factor here (FOSTER & KIRTLEY 1959 HIERTONN 1961) however many (BIER 1906 HUTCHISON & BURDEAUX 1954 STEIN *et al* 1958 HILLMAN *et al* 1959 BIRNSTINGL 1962 COLT & IGER 1963) attach the utmost importance to it VANDERHOEFT & KELLY (1964) and KECK & KELLY (1965) speak also of a venous congestion meaning a cascade like recycling of mixed arterial and venous blood an active venous conges tion and consider this to underlie the stimulating effect

Experimental measurements of the blood flow indicate that this in the extremity as a whole is reduced distal to a fistula at least at first (COHEN *et al* 1948 ROBERTSON *et al* 1950 HENRIE *et al* 1959) It gradually in creases and can at times exceed the normal level (LEWIS 1940) Similar conditions concern the blood flow in individual skeletal parts distal of a

fistula At first a decrease (PAUPORTE *et al* 1958), thereafter an increase, however not up to the normal level (WEINMAN *et al* 1964, KECK & KELLY 1965)

It has been possible by angiography to establish a considerable development of both arterial and venous collaterals as well as a tendency to arborisation of periosteal and intra osseous small vessels (ROBERTSON *et al* 1950, KELLY *et al* 1959 HIERTONN 1961, VANDERHOEFT *et al* 1963, WEINMAN *et al* 1964 VANDERHOEFT & KELLY 1964)

Venous stasis increases the blood flow to the growth plate (KISHIKAWA 1936) and this creates increased protein concentration and more favourable oxygen conditions (HUTCHISON & BURDEAUX 1954), making possible a stimulation of growth Intra osseous blood flow measurements are contradictory concerning the haemodynamic conditions McPHERSON *et al* (1961), SHAW (1963, 1964), report increased flow, VALDERRAMA & TRUETA (1965) note the same change, although only initially HERZIG & ROOT (1959) cannot measure any changes WHITE & STEIN (1965) on the contrary assert a reduction to half the normal flow

3 Changed static and dynamic conditions

Pressure and tension

The classical HUETER VOLKMANN law was formulated in 1862 This states that a pressure on a long bone applied longitudinally inhibits growth, whereas a reduction of such a pressure or a tension accelerates it (ARKIN & KATZ 1956 point out that DELPECH as early as 1829 observed this phenomenon) OLLIER (1867) *inter al* was of the same opinion other views however were soon expressed in this matter WOLFF (1892) most eagerly opposed HUETER VOLKMANN's theory He maintained that both an increased pressure and an increased tension stimulate bone growth

The longitudinally exerted force that an active growth plate develops is great For *man* about 400 kg (BLOUNT & ZEIER 1952) for calf about 150 kg (STROBINO *et al* 1956) The longitudinal growth can be completely stopped providing a sufficiently powerful pressure is applied to the epiphysial growth plate MULLER (1928) and HAAS (1945) showed this experimentally with the aid of a wire loop around the growth plate experiments that were repeated by *inter al* GELBKE (1951) SIFFERT (1956), SIJBRANDIJ (1963) SIJBRANDIJ states that a pressure of about 3 kg is needed to stop the longitudinal growth at the proximal tibial epiphysis in rabbit The clinical application with the aid of metal staples was introduced by BLOUNT & CLARK (1949)

MULLER (1924) in animal experiments increased the loading on the

ulna by partial resection of the radius and could detect a reduction of the growth in length of the ulna Increased pressure was observed histologically by BRACARD (1932) to impede the maturation of the cartilaginous cells in the growth plate and by TRUETA & TRIAS (1961) to obstruct the normal progression of the metaphysial vascular loops

STROBINO *et al* (1956) state that the prevention of growth at increased pressure obeys an all-or none law but this is contradicted by others for instance ARKIN & KATZ (1956) and SIJBRANDIJ (1963) who emphasize that the inhibition varies according to the applied pressure and also that the epiphysial growth plate can resume normal function providing the pressure has not been too prolonged (HAAS 1945 BLOUNT & CLARK 1949 GELBKE 1951 BLOUNT & ZEIER 1952 TRUETA & TRIAS 1961) Actually very slight force can modify the growth in skeletal length according to *APPLETON (1934) and ARKIN & KATZ (1956) Thus the normal force of* gravity and the stresses that result from ordinary muscle activity have a retarding effect upon the longitudinal bone growth however, this is ac*celerated when those factors are eliminated OLLIER (1867) called atten*tion to the fact that the amputation stump in the lower extremity of children often shows accelerated skeletal growth and he reports an elongation of humerus in rabbit after experimental resection of radius MULLER (1924) observed in experiments in rats where one hind leg was placed beneath the abdominal skin an elongation of the bones involved this he attributed to the elimination of normal pressure and tension Similar results were reported by ARKIN & KATZ (1956) at plastering experiments on rabbits BRASHEAR (1963) noticed an elongation of femur in rat after knee disarticulation Division of the tendons around the ankle produced a significant increase in the length of rabbit tibia (RING 1961)

HAAS (1917) however perceived scarcely any effect from plastering one hind leg in dog similar findings were reported by BERGMANN (1931) at experimental luxations or division of tendons Both these authors state as did RING (1957 1958 b) and SELYE & BAJUSZ (1958) later that the normal growth in length occurs independent of mechanical elements

The next stage in the experimental work was to expose a growing bone to tension The reports here however are few VON LANGENBECK (1869) thought that the fibular lengthening seen when the tibia in the same extremity increased in length because of inflammatory irritation was due to a purely mechanical tension SMITH & CUNNINGHAM (1957), applying distracting forces to the epiphyses of calves could measure accelerated bone growth whereas GELBKE (1951) who exposed apophyses (tuberositas tibiae olecranon in dog) to tension, failed to do this The histological picture on the contrary agreed more with that found in a growth plate exposed to increased pressure HAAS (1958) obtained similar results

Whereas the mentioned investigators attribute the changed growth rate that can be seen after exarticulation, luxation, plastering, &c., to the influence of the purely mechanical elements on the cells of the growth plate, another group of authors have assigned greater importance to the immobilization, i.e. the reduced or eliminated muscle activity resulting from such measures (RING 1961 *inter al.*). No differentiation of the underlying causal factors has thus been made but different forms of motor nerve injuries, *inter alia*, polio (see these sections) have also been included here. The retarding effect upon the longitudinal growth has attracted most interest (OLLIER 1867, ALLISON & BROOKS 1921, GILL 1944, GILLESPIE 1954, GEISER 1957, HUTH & WESTERBORN 1963, LANDRY & FLEISCH 1964, ANDYUSICHEVA 1964).

The causal relationship

The investigators who studied the bone growth at *changed pressure and tension conditions* have sought the explanation of the obtained effects exclusively in changed mechanical demands on the growth zones of bone. As appears from the foregoing, however, the experimental methods are here to a great extent identical with those used at various immobilization experiments. Thus different theories regarding the mechanism behind growth changes, secondary to such measures, have been combined in the next section.

Immobilization. The relation between muscle atrophy and growth retardation at disuse has been indicated (ARMSTRONG 1946, STINCHFIELD *et al.* 1949, GULLICKSON *et al.* 1950, RING 1957, 1961, RATLIFF 1959, KHARMOSH & SAVILLE 1965). GULLICKSON *et al.* (1950) maintain that skeletal growth is related more to the activity of the extremity than to the absolute muscular strength. Variations of this below the contraction level seem to have little importance, at least for the growth retardation (RING 1957).

As already mentioned, many regard bone and cartilage with surrounding musculature as a functional unit where a normal muscular activity regulates the formation as well as the destruction of the bone component by way of the vascular system. GILL's (1944) observation that a long term plastering of an extremity in children can lead to premature ossification of the epiphysial cartilaginous plates involved led GEISER (1957) to try to verify this experimentally. Plastering one hind leg or partially excising the Achilles tendon in a growing rabbit resulted in retarded growth in length, caused by premature ossification of growth plates and pronounced osteoporosis. GEISER suggests, as did TRUETA (1964) and VALDERRAMA & TRUETA (1965)

later with more emphasis that the balance in the osteogenetic function is upset by disturbance of the muscular pump activity on the venous back flow from the skeleton whereby the bone destruction will predominate and ossification of the cartilaginous growth plate will be accelerated Faradic stimulation of the plastered musculature considerably inhibited the mentioned effect of the immobilization and the removal of the plaster was followed by a partial reconstruction of the skeletal part involved However GEISER & TRUETA earlier (1958) referring to identical experiments maintained that the mechanical pressure forces produced by muscle action to counteract gravity seem to be a most important factor for the maintenance of bone structure

HEANEY (1962) stated that severe paralytic immobilization in an early phase shows signs of normal or increased bone formation rate and increased bone resorption rate A second phase replaces this with normal or subnormal activity in both respects LANDRY & FLEISH (1964) and KHARMOSH & SAVILLE (1965) have published experimental results that also indicate a higher activity ratio in an immobilized skeletal part during the first 2 to 4 weeks and a subnormal one in a later phase The bone resorption however is predominant

Changes in the vascular component in the bone muscle complex besides disturbed haemodynamic conditions here at immobilization are illustrated in various ways

Direct blood flow measurements indicate that an immobilization of an extremity leads to an increased arterial blood flow in it (IMIG et al 1953) at least initially (KEMP et al 1947) HULTH & OLERUD (1960) noticed by angiography signs of increased blood flow together with a dilatation of the large vascular trunks with a tendency to increased tortuosity microangiographic investigation disclosed hypervascularization of muscle fasciae and of the connective tissue in the distal part of the extremity (HULTH & OLERUD 1961) The venous blood flow in a plaster bandaged limb is considered to be increased in more than half of the cases (SCHRODER & SEYFARTH 1960)

GEISER (1957) and GEISER & TRUETA (1958) establish with the aid of injection methods that at immobilization a hypervascularization of the skeletal part involved occurs in conjunction with bone destruction but that bone formation too is accompanied by increased vascular activity Investigations of intramedullary blood disclose changes in its acid base status (HULTH & SEMB 1966 SEMB 1966 a) as well as increased values of HbO and pO (SEMB 1966 b) after about 10 days immobilization which is interpreted as signs of increased blood flow here Blood flow measurement with the aid of plasma clearance of Sr by bone also indicates increased intra osseous blood flow but not until after about two weeks of immobilization (SEMB 1966 c)

HULTH & WESTERBORN (1963), however judging by reduced uptake of S in the epiphysial cartilaginous plate suppose that the nutritive circulation in the metaphysis is reduced during the first days of an immobilization and SHIM (1966) using bone clearance of radiostrontium notes a reduced flow in tibia and calcaneus in rabbit after two weeks of plaster immobilization Prolonged immobilization however leads to a relative increase in the blood flow

SCHEDEL (1958) using oscillography, found in *homo* a circulation less than normal in a plastered extremity and angiographic investigation disclosed a narrowing of arteries and veins HULTEN's (1951) investigations also indicated a reduced flow but mainly in the skin vessels.

C GENERAL SURVEY OF ACCELERATED BONE GROWTH

For clarity a schematic list is given of examples found in the literature relating to accelerated bone growth and of theories advanced concerning the underlying mechanism

A *Stimulation of longitudinal bone growth by direct measures*

Röntgen BALNACH (1935)

Heat WILSON & THOMSON (1939) BERTRAND & TRILLAT (1948) RICHARDS & STOFER (1959) DOYLE & SMART (1963)

Trauma to the medullary cavity FERGUSON (1933) KISHIKAWA (1936) HUTCHISON & BURDEAUX (1954)

Application of various materials in the medullary cavity VON LANGENBECK (1869) MEISENBACH (1910) KONIGSWIESER (1925) BERGMANN (1931) KISHIKAWA (1936) PEASE (1952) TRUETA (1953 1958) CARPENTER & DALTON (1956) WILSON & PERCY (1956) NORDENTOFT & GULDHAMMER (1964)

Periosteal stripping OLLIER (1867) WU & MILTNER (1937) LACROIX (1947) BERTRAND & TRILLAT (1948) ZANOLI (1949) PEASE (1952) BRODIN (1955) LANGENSKIOLD (1957) TAILLARD (1959) ELO (1960) SOLA *et al* (1963)

Fracture TRUESDELL (1921) BURDICK & SIRIS (1923) COLE (1925) LEVANDER (1929) BISGARD (1936) COMPERE & ADAMS (1937) AITKEN *et al* (1939) HEDBERG (1945) BERTRAND & TRILLAT (1948) TRUETA (1953) GREVILLE & JANES (1957) EMNEUS & WIBERG 1958) GOFF (1960) WRAY & GOODMAN (1961) GULDHAMMER (1963)

The stimulated longitudinal bone growth is considered to be due to

Liberation of growth stimulating substance at periosteal stripping (LACROIX 1947 TAILLARD 1959) fracture (WRAY & GOODMAN 1961)

Changed circulatory conditions through

a) *interruption of the metaphysial blood flow* at trauma to the medullary cavity (FERGUSON 1933)
b) *hyperaemia* at heat (RICHARDS & STOFER 1959) trauma to and application of various materials in the medullary cavity (VON LANGENBECK 1869 KONIGSWIESER 1925 KISHIKAWA 1936 CHAPCHAL & ZELDENRUST 1948 PEASE 1952, HANSSON & WIBERG 1963) fracture (LEVANDER 1929 BISGARD 1936 HEDBERG 1945 BERTRAND & TRILLAT 1948)
c) *increased circulation in epiphysial and metaphysial vessels* at trauma to and application of various materials in the medullary cavity (TRUETA 1953 CARPENTER & DALTON 1956) periosteal stripping (BRODIN 1955 SOLA *et al* 1963) fracture (TRUETA 1953 CAVADIAS & TRUETA 1965)
d) *venous stasis* at trauma to and application of various materials in the medullary cavity (HUTCHISON & BURDEAUX 1954)

B Stimulation of longitudinal bone growth by indirect measures

Disturbed innervation

a) *motor nerve injury* RING *(1961)*
b) injury of sympathetic nervous system pharmacological sympathetic blockade HARRIS & MCDONALD (1936) KISHIKAWA (1936) BARR *et al* (1950) GULLICKSON *et al* (1951) GOETZ *et al* (1955) KOTTKE *et al* (1958)
c) sectioning of peripheral nerve MILNE EDWARDS *(1860)* OLLIER *(1867)* NASSE (1880) GHILLINI (1898) RING (1961)
d) poliomyelitis SEELIGMULLER (1879) GREEN & ANDERSON (1955) LERIQUE (1956) RING & WARD (1958) RATLIFF (1959)

Disturbed circulation

a) increase of the arterial circulation DICKERSON (1966)
b) arterio-venous fistula BROCA *(1856)* FRANZ *(1905)* HORTON *(1932)* HARRIS & MCDONALD (1936) JANES & MUSGROVE (1950) HIERTONN (1957 1961) DOERR & JANES (1959) KELLY *et al* (1959) COOLEY *et al* (1960) JANES & JENNINGS (1961) BIRNSTINGL (1962) VANDERHOEFT *et al* (1963) KECK & KELLY (1965)

c venous stasis HELFERICH (1887) SCHULLER (1889) KLIPPEL & TRENAUNAY (1900) BOREL (1922) PEARSE & MORTON (1930) BERGMANN (1931) KISHIKAWA (1936) SERVELLE (1948) HUTCHISON & BURDEAUX (1954) FOSTER & KIRTLEY (1959) COLT & IGER (1963)

Changed static and dynamic conditions

a) reduced pressure OLLIER (1867) MULLER (1924) ARKIN & KATZ (1956) RING (1961) BRASHEAR (1963)
b) tension VON LANGENBECK (1869) SMITH & CUNNINGHAM (1957)

The stimulated longitudinal growth is considered to be due to

Trophic disturbance at injury to the motor innervation (SEELIGMULLER 1879)

Reduced pressure on the growth plate at injury to the motor innervation (OLLIER 1867 SEELIGMULLER 1879 NASSE 1880, GHILLINI 1897, RING & WARD 1958 RING 1961) at elimination of normal pressure and tension forces and normal muscle activity (OLLIER 1867, MULLER 1924, ARKIN & KATZ 1956 RING 1961 BRASHEAR 1963) at tension (VON LANGENBECK 1869 SMITH & CUNNINGHAM 1957)

Increased blood supply to the growth plate through

a) *shunting of blood* from musculature to skeleton at defective motor innervation (RING & WARD 1958 FANCONI 1959 RING 1961 TROUPP 1961)
b) *arterial hyperaemia* at diversion of an arterial channel into bone (WOODHOUSE 1963) at arterio-venous fistula (JANES & MUSGROVE 1950 HOLMAN 1955 DOERR & JANES 1959 HIERTONN 1961)
c) *vasodilatation* at sympathectomy of pharmacological sympathetic blockade (HARRIS & MCDONALD 1936 KISHIKAWA 1936 GULLICKSON *et al* 1951 GOETZ *et al* 1955)
d) *venous stasis* at arterio-venous fistula (BIER 1906 HUTCHISON & BURDEAUX 1954 STEIN *et al* 1958 FOSTER & KIRTLEY 1959 HILLMAN *et al* 1959 HIERTONN 1961 BIRNSTINGL 1962 COLT & IGER 1963, VANDERHOEFT & KELLY 1964 KECK & KELLY 1965) *venous occlusion* (KISHIKAWA 1936 HUTCHISON & BURDEAUX 1954)

D COMMENTS

An explanation of the sometimes extremely controversial results obtained experimentally in an effort to accelerate the growth in skeletal length can be sought in various methodological errors

Little notice has usually been paid to the age of the experimental animals and the growth potential associated with it. In many instances all that has been mentioned is that it was a "young" or a "growing" animal (Table 1). Moreover, some authors express the recorded difference in length in per cent of the length of the whole skeletal part, whereby comparisons with results from experimental animals of other age or other species cannot be made. RING (1961) mentions only the length of the diaphysis, making comparisons with measurements of the entire skeletal part impossible. Several investigators have measured the whole extremity or a part of it (e.g. the foot skeleton). This complicates comparisons with results concerning individual skeletal parts; moreover, the elasticity of a joint could influence the accuracy of the measurements.

The precision of the measuring method is fundamentally important. Several investigators fail to mention their procedure. Except for caliper measurements, the röntgenologic method is the most used. This is sometimes combined with radiopaque markers in the diaphysis, by which the contribution of the individual growth plates to the recorded length difference is determined. Few authors have discussed the size of the error in measurement with this method. LANGENSKIÖLD (1957) gives it as 1 mm, RING (1961) as 0.5 mm, BRODIN (1955) as 0.3 mm. BRODIN, however, bases this margin of error on comparisons with length measurements made directly on the bone with a slide caliper, which, as he himself points out, does not give exact values. FLO (1960) used a modified method according to Brodin and estimates the error at 0.1 mm. Length measurements with the aid of calipers are also affected by errors in measurement, which most authors make no comment on. GREVILLE & JANES (1957) are among those who estimated it at 1 mm; the corresponding dimension is given by RING & LEE (1958) as 0.5 mm. RING (1961) considers the figure to be lower but fails to specify it more closely.

The size of the measurement error must then be seen in relation to the noted effects of various experimental procedures (Table 1).

A contributing cause of the varying results of growth stimulating operations can be the highly varied observation periods. With few exceptions, the investigators in the surveyed literature have made the measurements at the earliest two weeks after the operation, and often several weeks or months after. If the stimulating effect appears at an early stage in the experimental period and is later followed by a period of retarded growth analogous to the findings made concerning the sequelae of poliomyelitis (see above), the time point for the observation can be of essential importance.

Table 1 Experimental attempts to stimulate the longitudinal bone growth. Unless otherwise stated, the experimental procedure was directed toward the investigated skeletal part. When change in growth is expressed in per cent, the comparison has been made with the contralateral side

Author	Year	Animal (number)	Age	Procedure	Investigated bone	Measuring method	Effect (mm)	Obs. time
Baunach	193[illegible]	rabbit (20)	young	rtg	femur	rtg	+2	1 [illegible] month
Liddle & Kimeldorf	1966	rat (120)		(whole body dose)	tibia		neg	2 months
Wise et al	1949	rat (10)	young	heat	femur	rtg	0 or neg	2–36 weeks
De Forest et al	1953	rabbit (29)	3–8 weeks		tibia	caliper	+3–26	2–18 weeks
De Forest et al	1953	dog (9)	1–8 months				−3–21	21–29 weeks
Ring & Lee	1958	rabbit (15)	2–3 months		ulna		0 or neg	1–31 days
Richards & Stofer	1959	rat (17)	25 days		femur	caliper?	+6 %	30–40 days
Richards & Stofer	1959	dog (5)	6–8 weeks				+2.2 %	30–40 days
Doyle & Smart	1963	rat (11)	21 days			caliper	+0.2–0.8	40 days
Doyle & Smart	1963	rat (11)	21 days		tibia		−0.2–+2.1	40 days
Cranberry & Janes	1963	dog (7)	1–5 months		femur	rtg	+0.15	63 days
Cranberry & Janes	1963	dog (7)	1–5 months		tibia		+0.1	63 days
Kishikawa	1936	rabbit (?)	young	trauma to medullary cavity (tibia)	hind leg	?	+1.77	4 weeks
Compere & Adams	1937	(5)	3 weeks	trauma to medullary cavity (femur)	femur + tibia	caliper	0	10–77 days
Wu & Miltner	1937	(6)	[illegible]–8 weeks	trauma to medullary cavity	tibia	rtg	insignificant	3–6 months
Hutchison & Burdeaux	1954	dog (10)	3 months		femur	caliper	+0.8 %	16–110 days
Hansson & Winero	1963	rabbit (27)	30 days		tibia		+0.5 (insign.)	5–61 days
Langenbeck	1869	dog (1)	8 weeks	application of different material in medullary cavity	femur	?	+5	3 months
Langenbeck	1869		8 weeks		tibia	?	+5	3 months
Trout	1915	rabbit (10)	1–6 weeks			?	0 or neg	6 months

Meisenbach	1910		(29)	6 weeks			rtg	pos	2—12 weeks
Bohlman	19[illegible]9	guinea pig (92)		young		femur	caliper?	0 or neg	3 months
Bergmann	1931	dog (2)		6 weeks			?	— 1	1—4 months
Bergmann	1931			6 weeks		tibia	?	± 1	1—4 months
Bergmann	1931	rabbit (7)		young		femur	?	± 1	6—9 weeks
Bergmann	1931					tibia	?	— 2—+ 1	6—9 weeks
Kishikawa	1936		(?)			hind leg	?	+ [illegible]07	6—16 weeks
Wu & Miltner	1937		(10)	5—8 weeks	(femur + tibia) application of different material in medullary cavity	tibia	rtg	insignificant	1—3 months
Chapchal & Zeldenrust	1918		(14)	6—12 weeks		femur		— 3 5—+ 4	3 months
Herndon & Spencer	19[illegible]3		(10)	3—4 weeks			caliper	varied	6 months
Wilson & Percy	19[illegible]6	dog (46)		10—14 weeks		tibia	rtg	+ 1—[illegible]	1—4 months
Haas	19[illegible]8	rabbit (6)		growing		radius	?	0	?
Ollier	1867	rabbit (3)		young?	periosteal stripping	tibia	?	+ 2—5	3 months
Wu & Miltner	1937	"	(18)	5—8 weeks			rtg	significant	20 days—[illegible] months
Sousa Pereira	1938		(2)	6—8 weeks		ulna		neg	41 days—6 1/2 months
Lacroix	1947		(8)	35 days		tibia		+ 1—2 3	?—8 months
Bertrand & Tellat	1948	guinea pig (1[illegible])		young			?	0—17	3 months
Brocck	19[illegible]	rabbit (44)		"			rtg	+ 0 1—0 [illegible][1] + 0 1—0 9[2]	1 week
Langenskiöld	19[illegible]	"	(7)	14—36 days				+ 1—3	1—8 weeks
Ito	19[illegible]0	"	(14)	2—6 weeks				— ?—+ 0 7	3—[illegible]3 weeks
et al	19[illegible]3	dog (3[illegible])		3—4 months		femur + tibia	caliper	+ 1 6	8—9 months
[illegible]	19[illegible]9	rabbit (13)		2—4 months	fracture (tibia)	femur	rtg	+ [illegible]	1—9 months
	[illegible]	goat (23)		3 months	"	tibia		0—+ [illegible]5	1—11 weeks

Author	Year	Animal (number)	Age	Procedure	Investigated bone	Measuring method	Effect (mm)	Obs. time
LOMPERT & ADAMS	1937	rabbit (1)	7 weeks				pos. (insignificant)	[illegible] weeks
CREVELLI & JANES	1957	dog (20)	3—4 months		femur	caliper	+ 2.4—11	6—9 months
WRAY & GOODMAN	1961	rat (144)	young	(tibia)			+ [illegible]	3—18 days
GREY & CARR	1915	dog (1)	?	posterior root sectioning	tibia	rtg	0	2 1/2 months
GILLESPIE	1954	cat (10)	young		femur + tibia		0 or neg	2 months
RING	1961	rabbit (31)		peripheral sensory denervation	tibia	caliper	0	2—16 weeks
TROUPP	1961	(11)	13—17 days	posterior root sectioning	femur		− 6—21 %	1—12 weeks
TROUPP	1961		13—17 days		tibia		0	1—12 weeks
GREY & CARR	1915	dog (1)	?	anterior root sectioning	tibia	rtg	0	1—10 weeks
GILLESPIE	1954	cat (10)	young		femur + tibia		0 or neg	2 months
RING	1961	(16)			tibia	caliper	0—+1	3—6 weeks
RING	1961	dog (21)					0—+1	3 months
TROUPP	1961	rabbit (19)	13—17 days		femur		− 5	1—12 weeks
TROUPP	1961		13—17 days		tibia		− 2.5 %	1—12 weeks
BACQ	1930	rat (9)	young	sympathectomy	hind leg	?	0	3 months
BERGMANN	1931	dog (3)			tibia	?	0	1 month
BISDARD	1931	goat (1)				rtg	0	2—6 months
HARRIS & McDONALD	1936	cat (10)			hind leg	?	0	?
HARRIS & McDONALD	1936	dog (12)				?	0	?
KISHIKAWA	1936	(?)				?	0	?
GULLICKSON et al.	1951	dog (6)				?	+ 6.5	?
GOETZ et al.	1955	rabbit (?)			hind paw	rtg	+ 4 %	14—80 days
RING	1961	dog (11)			tibia	caliper	0—+1	3 months
TROUPP	1961	rabbit (16)	13—17 days				0	4 weeks
TROUPP	1961		13—17 days		femur		0	4 weeks

Milne Edwards	1860	dog (1)	8 months	peripheral nerve sectioning	mandibula	?	pos	5 weeks
Ollier	1867	cat (3)	3 days		tibia	?	+ 0.5	7 days
Nasse	1880	dog (7)	young		metatarsals	?	pos	2—8 months
Ghillini	1897	rabbit (?)	2 months		hind leg	?	0	6 weeks
Howell	1917	dog (?)	4 weeks		fore leg	rtg	− 5.5	19 weeks
Allison & Brooks	1921	(13)	young		humerus	rtg	neg	10—200 days
Bergmann	1931	(3)	7 weeks		hind leg	?	0	?—10 weeks
Armstrong	1946	rat (8)	27 days		humerus	rtg	− 0.5	1—15 weeks
Armstrong	1946		27 days		radius		− 1.7	1—15 weeks
Gillespie	1954	(16)	young		femur + tibia		0	4 weeks
Sfive & Bajusz	1958	(10)			tibia	caliper	0	30 days
Landry & Fleisch	1964	(16)			femur + tibia	?	0	12 days—5 months
Dickerson	1966	dog (16)	3—4 months	implantation of artery	femur	rtg	0—+ 2	14—1?0 days
Janes & Musgrove	1950	dog (10)	6 months	a v fistula (iliac)	femur	?	pos (90)	3—15 months
Janes & Musgrove	1950		6 months		tibia	?	pos (60)	3—15 months
Doerr & Janes	1959	(15)	4 months	(femoral)	femur + tibia	?	+ 1—6	14 months
Kelly et al	1959	(1?)	3—4 months	(iliac or femoral)	femur	?	+ 1—5	9—15 months
Kelly et al	1959		3—4 months		tibia	?	+ 2.5—4	9—15 months
Vanderhoeft et al	1963	(7)	3—4 months	(femoral)	femur + tibia	?	+ 5	6—18 months
Keck & Kelly	1965	(9)	4—6 weeks		femur + tibia	rtg	pos	6 months
Grey & Carr	1915	dog (1)		venous stasis (lig subclavian vein)	fore leg	rtg	0	? months
Borel	192?	rabbit (3)	5 weeks	venous stasis (lig femoral vein)	femur	?	+ 1	3—4 months
Borel	192?		5 weeks		tibia	?	+ 1—1	3—4 months
Kishikawa	1936	(?)	young		hind leg		+ 1.77	4—9 weeks
Servelle	1948	dog (7)	1 month		tibia	?	+ 2—8	12—18 months
Dickinson	1953	(8)	6 weeks	venous stasis (lig ext iliac vein)	hind leg	rtg	0	3—4 months

Author	Year	Animal (number)	Age	Procedure	Investigated bone	Measuring method	Effect (mm)	Obs time
HUTCHISON & BURDEAUX	1954	dog (11)	3 months	venous stasis (tourniquet)	radius	*caliper*	+ 1.04 %	18—132 days
HUTCHISON & BURDEAUX	1954		3 months		femur		+ 0.52 %	25—75 days
HUTCHISON & BURDEAUX	1954		3 months		tibia		+ 1.45 %	25—75 days
COLT & ILER	1963	(10)	young	venous stasis (stenosis of *femoral vein*)	femur	?	0—+ 2	8—10 months
COLT & ILER	1963				tibia	?	0—+ 1.5	8—10 months
KECK & KELLY	1965	(25)	2 1/2—6 months	venous stasis (lig. inf. vena cava + right femoral vein)	femur + tibia	rtg	0	6 months
MÜLLER	1924	dog (3)	young	pressure (resection of radius)	ulna	rtg	neg	10—70 days
MÜLLER	1928	(?)			femur		— 12	2 *months*
MÜLLER	1928				tibia		— 11	2 months
HAAS	1945	(7)	growing		radius		— 10	55 days
GELBKE	1951	(?)			femur		— 15	19 weeks
GELBKE	1951	dog (?)	growing	tension	apophyses	rtg	0	19 weeks
SMITH & CUNNINGHAM	1957	calf (7)			prox. tibia		+ 3	30 days
HAAS	1958	rabbit (?)			femur	?	0	?
HAAS	1958				tibia	?	0	?
HAAS	1917	dog (5)	5—7 weeks	plaster	metacarpals	?	0—+ 1	12—42 days
ALLISON & BROOKS	1921	(4)	young		humerus	rtg	neg	10—200 days
ARKIN & KATZ	1956	rabbit (15)	6—8 weeks		tibia		+ 3	3—6 weeks
HULTH & WESTERBORN	1963	(34)	young		radius		— 1	2 hours—20 days
BERGMANN	1931	dog (3)	5 weeks	muscle + tendon sectioning (knee)	tibia	?	— 2	2—16 weeks
RING	1961	rabbit (17)	young	tendon sectioning (ankle)	tibia	caliper	+ 3	3—6 weeks

Avdunicheva	1964	dog (25)		muscle or tendon sectioning	?	?	neg	?
Avdunicheva	1964	cat (15)			?	?	neg	?
Avdunicheva	1964	rat (120)			?	?	neg	?
Ollier	1867	rabbit (1)	young	resection of radius	humerus	?	+ 1	5 months
Bergmann	1931	dog (2)	7 weeks	luxation (hip)	tibia	?	− 1—0	3—5 weeks
Bergmann	1931	rabbit (2)	8 weeks			?	0	2—5 weeks
Brashear	1963	rat (57)	young	(knee)	femur	caliper	− 0.4—+ 0.8	1—92 days
Müller	1974	rat (?)	young	limb beneath abdominal skin	radius ulna tibia	rtg	+ 1—2.5	1 1/2 months

[1] from the proximal growth plate
[2] from the distal growth plate

As mentioned earlier big differences of opinion exist concerning the effect of sympathectomy on the longitudinal bone growth Decisive for the experimental result is naturally to what extent the sympathectomy has been completed in the investigated region Whereas several authors (BERGMANN 1931 KISHIKAWA 1936 GULLICKSON *et al* 1951 RING 1961 TROUPP 1961) have completely omitted to check the extent of the sympathetic denervation BACQ (1930) after resection of the lumbosacral sympathetic trunk in rat carried out post mortal examination of the operation field and omitted those instances where the intended ganglionectomy had not been complete However the rat has a large number of so called intermediate ganglia distributed in the lower thoracic lumbar and upper sacral region (WRETE 1941) These intermediate ganglia are not found in a definite anatomical localization but sometimes along the ramus communicans sometimes at the paravertebral ganglion and sometimes at the spinal nerve Their preganglionic and postganglionic connexions can vary and it is possible that a resection of the sympathetic trunk can leave them completely intact, resulting in an incomplete sympathectomy (WRETE 1941 MONRO 1959) Furthermore skin temperature measurements (BISGARD 1931) sometimes after pre cooling (GOETZ *et al* 1955) have been used as a test of sympathetic denervation as has pilo erection after exposure to cold (CANNON *et al* 1929) These methods however seem to provide scanty information concerning the degree of sympathetic denervation

Finally all results of the various investigations must also be appraised with reference to the size of the examined experimental groups (Table 1)

II Own investigations

A PURPOSE OF THE INVESTIGATIONS

The aim was to try to accelerate the longitudinal growth of the tibia in growing rabbit The author thought it of importance to use here a growth stimulating method whose effect on the bone growth could to as great an extent as possible be analysed concerning the active factors involved From this standpoint an indirectly acting stimulation method one that avoided direct trauma to the bone was thought most suitable

Previous investigations of growth disturbances in the skeleton after various nerve injuries indicate a relation with nervous functions it has also been noted that the bones involved usually show increased growth in the initial phase after poliomyelitis in children This gave the author the idea of attempting to influence the bone growth by experimental nerve injury— avoiding at the same time local effect on the bone by the experimental

measure—and to record changed growth conditions during the immediate post-operative period

At first the effect on the bone growth by sectioning peripheral nerves was studied. As pointed out earlier this means an interruption of motor, sensory and postganglionic sympathetic nerve fibres. With the object of trying to analyse the effect on the growth rate of these various components the author carried out in later experiments a selective motor nerve injury by sectioning anterior roots, a sensory nerve injury by sectioning posterior roots and an interruption of the sympathetic innervation by sympathetic ganglionectomy.

It has previously been discussed whether injury to motor nerve fibres besides a disturbed neuromuscular function, also disturbs possible neurotrophic influence on the skeleton. With the object of producing defective muscular function with retained innervation and thereby avoiding this trophic factor, a resection of a part of the Achilles tendon was next carried out.

Because the trauma after the various experimental measures proved in general to have primarily a retarding effect on the skeletal growth, the observations first began on the third post-operative day when this effect seemed to have subsided.

B. MATERIAL—GENERAL

The material consisted of white rabbits aged—with few exceptions—6 weeks ±2 days. The litter usually lived with the mother animal. At the experiments neither the weight of the animal, the litter nor the sex were taken into account (see statistical analysis). Every animal that at ocular examination showed the slightest symptom of illness was excluded from the material. All animals were raised on rabbit pellets and water ad libitum.

C. MEASURING METHOD FOR LONGITUDINAL BONE GROWTH. HISTOTECHNICAL METHOD

In the following experiments the endochondral growth from the proximal growth plate of the diaphysis towards the metaphysis in the growing rabbit tibia was used as indicator of the longitudinal growth of this bone. The author employed the measuring method described by HULTH & OLERUD (1962), HANSSON (1964); this consists of intravital labelling of cartilage and bone tissue with the aid of tetracycline. Oxytetracycline (Terramycin Pfizer) was administered intravenously in a dose of 1 mg/kg body weight. With this dosage for rabbit no toxic effects on cartilage or bone tissue could be observed (HANSSON 1967).

Oxytetracycline was given to the experimental animals in two intravenous injections with 24 hour interval. The animals were killed by a blow on the neck 10 minutes after the second injection. The proximal parts of the two tibiae were dissected out and fixed in absolute alcohol for 24 hours. The articular surfaces as well as the cortical bone with the exception of the cortical layer on the dorsal aspect were removed from the preparation with a dental saw; the preparation was then embedded in paraffin in the usual way. Resting on the dorsal surfaces of the tibial condyles it was then mounted on a wooden block in a sliding microtome. A small lateral part of one condyle was cut away sagittally with a knife. The thus produced sectional area was deparaffined and stained superficially with haematoxylin after which the bone trabeculae in the metaphysis could easily be studied with the aid of a dissection microscope. By levelling the trabeculae parallel to the sectioning plane of the microtome an oblique cutting of the mentioned trabeculae in their longitudinal extension was avoided. To prevent breaks in the section at the conventional stretching procedure it was caught on tape according to the RYDBERG (1955) method. The sections 60 μ thick were mounted adhering to the tape in Entellan (Merck, Darmstadt) containing xylene (1 : 10) to dissolve the paraffin in the sections. This mounting material similar to ordinary commercial tape does not autofluoresce.

The sections were investigated in a Zeiss fluorescence microscope. The UV light from a high pressure mercury lamp (Osram HBO 200) was passed through a Schott UG 1 filter and the light emitted from the section was filtered through a Schott GG 9 filter.

At the microscopic examination two fluorescent bands of oxytetracycline could be observed on the metaphysial side of the growth plate. They indicate the endochondral longitudinal growth here during the interval between the two injections, i.e. 24 hours (Fig. 1). The distance between the diaphyseal frontiers of the two lines was measured with a measuring ocular. In order to reduce the possible errors measurements were made only in those parts of the section where the fluorescent lines formed a right angle to unbroken bone trabeculae. Thus 15 measurements were made in different sections from one and the same preparation and the arithmetic mean obtained was used at the later calculation.

Further the 15 observations from 24 animals were used in a variance component model for estimating the precision of the measuring method. The calculations indicate that the arithmetic mean ± 5 μ is a 95 % confidence interval.

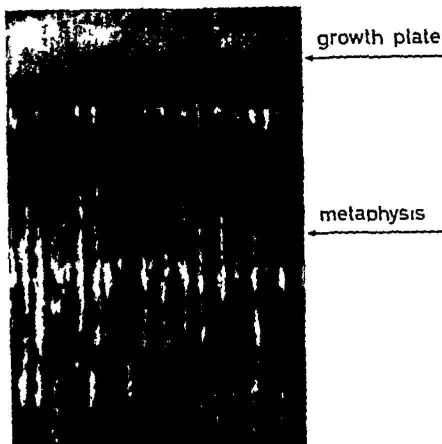


Fig 1 Fluorescent microphotograph of the proximal tibial metaphysis in growing rabbit The animal was given 2 injections of oxytetracycline with a 24 hour interval It was killed 10 minutes after the second injection The oxytetracycline appears as two fluorescent transversal bands located in the metaphysis The distance between the diaphysial frontiers of the bands represents the longitudinal growth from the cartilaginous plate towards the metaphysis during the interval between the two injections Magnification 79×

D METHOD FOR CONTROL OF SYMPATHETIC DENERVATION

As indicated above (p 36) previous experimental works concerning the effect of sympathectomy on bone growth can be criticised as far as the lack of control of the extent of denervation is concerned The use of a method that reveals an incomplete denervation must be regarded as an absolute necessity Based on this the author after experimental injury to sympathetic nerve fibres has appraised the degree of denervation by noting the disappearance of noradrenalin from the autonomic groundplexus of the intramedullary blood vessels (EULER & PURKHOLD 1951)

Noradrenalin identified as the transmitter substance in the peripheral adrenergic system and known to occur throughout the entire neuron but stored in especially high concentration in the nerve terminals (see EULER 1946 1961) can be studied at the cellular level with FALCK & HILLARP's fluorescence method for demonstration of certain biogenic monoamines (FALCK 1962 FALCK *et al* 1962 CORRODI & HILLARP 1963 1964) A detailed methodological description has been given by FALCK & OWMAN (1965)

After postganglionic sympathectomy the noradrenalin disappears owing to a massive leakage from the adrenergic nerves (EULER & PURKHOLD 1951) a process that begins in rat 8—24 hours after axotomy and is thereafter completed in 1—2 hours (MALMFORS & SACHS 1965) The course, interpreted as a consequence of degenerative processes in the nerve fibres seems to be somewhat slower in other species (KIRPEKAR *et al* 1962) Despite the extremely high sensitivity of the fluorescence method for demonstrating noradrenalin (FALCK 1962) however a small amount of the amine can be thought to remain undetected towards the end of the mentioned leakage If such be the case this non visualizable quantity should have disappeared during the course of a further few hours

After systematic error has been excluded and an adequate time margin allowed it can thus be established that a total lack of fluorescent noradrenalin product in adrenergic nerves for 24 hours indicates a complete interruption of the functional connexion between the innervation apparatus and the receptors of the effector cells

The technique used by the author consisted of opening with a dental saw the medullary cavities in the two tibiae immediately after the animal had been killed With the aid of a dissection microscope, a number of arteries were dissected out from various parts of the two medullary cavities and placed on each side of an engraved marking line on one and the same slide It was easy to distinguish the arteries from the extremely thin walled veins The procedure with one slide ensured that the vessels from the two bones later underwent exactly the same treatment thereby the fluorescence intensity was directly comparable

Another slide covered the preparations the two slides being pressed together in a small vice Thus the tissue pieces were spread into thin membranes To avoid adhesion between the preparations and the covering slide a thin plastic separating film (PARAFILM M, American Can Comp) was placed here beforehand The slide with the thus tr[illegible] vessels was dried in a dessicator over phosph[illegible] then exposed to formaldehyde gas from p[illegible] ur After clearing in xylene for 5 minu[illegible] in



Fig 2 Fluorescent microphotographs showing whole mount preparations of tibial intra medullary arteries treated with formaldehyde Left sided lumbosacral sympathectomy 48 hours earlier The vessel from the control side shows a network of fluorescent terminal nerve fibres (A) whereas the vessel from the sypathectomized bone shows no specific fluorescence (B) Magnification 165×

Entellan (Merck Darmstadt) They could then be immediately examined in the fluorescence microscope The source of light was a high pressure mercury lamp and the UV light passed through a Schott BG 12 filter The light emitted by the preparation was filtered through a Schott OG 4 filter

A great many previous investigations with the fluorescence method confirm the presumption that the green to yellow green fluorescent network surrounding the vessels represents adrenergic nerve fibres running in a typical autonomic groundplexus Fig 2 shows intramedullary arteries from an animal that had undergone lumbosacral ganglionectomy 48 hours earlier (see page 58) The vessel from the sympathectomized bone shows no specific fluorescence whatsoever (Fig 2 B) whereas a moderately tight network of fluorescent terminal nerve fibres with its typical varicosities appears on the vessel from the non-operated bone (Fig 2 A) The width of the meshes however depends completely upon how much the vessel has been stretched at the compressing procedure and cannot be considered to reflect normal conditions A cross section of a similar freeze dried vessel is shown in Fig 3 (for details of the freeze drying method see FALCK & OWMAN 1965) The innervation apparatus appears as a superficial structure superimposed upon the media However a less complete picture of the innervation apparatus is obtained here compared with the whole mount preparation

E STATISTICAL ANALYSIS

Within each experimental group reported here there are for every investigation day six observations (six different animals) that indicate the noted

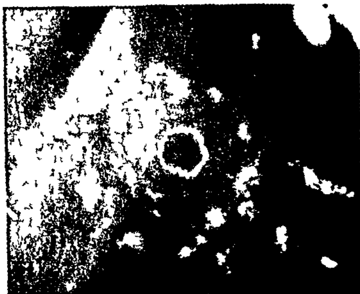


Fig 3 Fluorescent microphotograph of a tibial intramedullary artery (freeze dried) treated with formaldehyde Cross section (6 μ) The fluorescent innervation apparatus appears as a superficial structure superimposed upon the media The internal elastic membrane of the artery shows unspecific auto-fluorescence Magnification 300×

growth difference between operated and non operated side expressed in percentage of the non operated control side These observations are presumed to come from normal distributions whose means are a measure of the effect of the experimental method

The first observations were made in Group A during post-operative days 3 6 9 12 15 and 18 Six litters of six animals each were used here in the following manner (the animals belonging to one litter were randomly grouped)

Sub-groups	Litter number					
	1	2	3	4	5	6
A 3	3 animals	3 animals				
A 6	3 animals		3 animals			
A 9		3 animals	3 animal			
A 12				3 animals	3 animals	
A 15				3 animals		3 animals
A 18					3 animals	3 animals

One animal from another litter

Application of t test as well as of Aspin Welsh's test for A 9 showed no significant difference between litters regarding the experimental effect. Moreover, because it appeared that no variance stability worth mentioning was gained by working in litters, the material was instead grouped in days.

To investigate whether any relation existed between the experimental effects and the original weight of the animals or between the experimental effects and the relative increase in weight, corresponding correlation coefficients for the various subgroups within the entire Group A were calculated. These were

Subgroups	Effect *contra* original weight	Effect *contra* rel. weight incr.
3	−0.67	+0.63
4	+0.80	+0.35
5	−0.64	+0.06
6	+0.44	+0.69
7	−0.57	−0.52
8	+0.19	−0.17
9	−0.25	−0.03
12	−0.51	+0.05
15	+0.46	−0.23
18	−0.38	+0.28

If normal distribution presumptions are made and two-sided tests of the hypotheses that the correlations are zero are carried out, no significant deviation is obtained from these hypotheses. Further, if the many sign changes are noted, there is on the basis of the material produced no reason to presume that the effects are to any extent due to the weight of the animals or to their weight changes.

In the continued analysis of the Groups A, B, C, D and E, normal distributions with a common variance have been presumed. When the subgroups C 9 and E 18 show significantly less sample variances, they have been analysed separately. BARTLETT's M test was performed on the variances of the other subgroups without any significant deviation from the presumption about common variance being observed. The pooled variance estimate is 12.16 with 130 degrees of freedom.

Of the subgroups within the sham groups (A-, B-, C-, D- and E-sham) B-sham 9, D-sham 6 and E-sham 3, 9 have been analysed separately. BARTLETT's M test on the remaining subgroups gives no significance and the pooled variance estimate is 1.76 with 40 degrees of freedom.

Here the following code is used for significances
* 1 % < P < 5 % (probably significant)
** 0.1 % < P < 1 % (significant)
*** P < 0.1 % (highly significant)

F EXPERIMENTS

1 Sectioning of peripheral nerves

With the exception of some proximal muscle groups the skeletal musculature in the hind limbs of rabbit is innervated by the femoral and sciatic nerves which issue with certain variations from nerve roots of L L L and L S S respectively (KRAUSE 1868 CRAIGIE 1948)

Besides sensory and motor components such peripheral nerves contain, as mentioned sympathetic postganglionic fibres

The vascular nerve supply in the limbs follows two main patterns a) a nerve supply direct from the paravertebral sympathetic trunk to the large vascular trunks in the proximal parts of the limb b) a hereto connecting innervation to the more peripheral vascular ramifications through sympathetic fibres running in the spinal somatic nerves Thus the sympathetic nerves intended for structures distal to the knee are all found in the sciatic nerve (KRAMER & TODD 1914 WOOLLARD 1926 GASK & ROSS 1937 SHIM et al 1966 ZIMMERMAN 1966)

Denervation (Group 4)

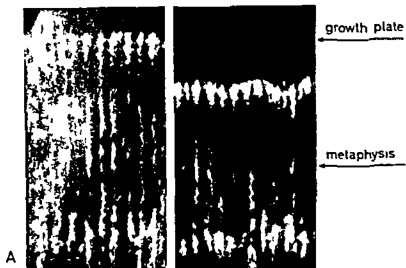
The animals were anaesthetized for the operation with 6 % Mebumal natrium (ACO) given intravenously in a dose of 1/2 ml/kg body weight complemented with ether After blunt dissection through covering musculature the sciatic nerve was exposed on the right side where it emerges underneath the piriform muscle sectioned and a half centimetre resected The right femoral nerve was sectioned and resected similarly just distal to the inguinal ligament The skin was sutured with perlon

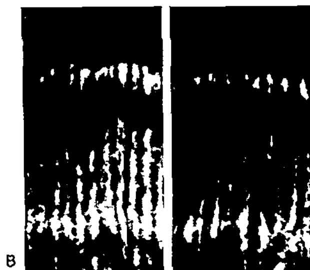
During the post-operative course the longitudinal bone growth was studied in the proximal parts of the tibiae with the aid of tetracycline labelling as described above The animals were killed at different times after the operation and were arranged in groups of six (see Table 2) Useful data were obtained from 60 animals

In 9 different animals distributed on the third sixth and ninth postoperative day the extent of the postganglionic sympathetic injury caused by the nerve sectioning was examined with the aid of the fluorescence method according to FALCK & HILLARP

Table 2 (Group A) Longitudinal growth in the proximal tibia in rabbit after peripheral nerve sectioning

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in % of non-op side
3	59/2	577.0	659.0	+ 82.0	+ 14.2
3	59/5	544.0	581.0	+ 37.0	+ 6.8
3	59/6	555.0	611.0	+ 56.0	+ 10.1
3	60/2	505.0	581.0	+ 76.0	+ 15.1
3	60/5	549.0	624.0	+ 75.0	+ 13.7
3	60/6	415.0	484.0	+ 69.0	+ 16.6
4	76/2	387.0	429.0	+ 42.0	+ 10.9
4	82/1	460.0	533.0	+ 73.0	+ 15.9
4	98/3	463.0	538.0	+ 75.0	+ 16.2
4	117/1	416.0	469.0	+ 53.0	+ 12.7
4	117/4	458.0	529.0	+ 71.0	+ 15.5
4	210/12	350.4	394.2	+ 43.8	+ 12.5
5	72/1	389.0	453.0	+ 64.0	+ 16.5
5	72/2	375.0	427.0	+ 52.0	+ 13.9
5	72/3	325.0	394.0	+ 69.0	+ 21.2
5	82/2	382.0	432.0	+ 50.0	+ 13.1
5	82/3	375.0	456.0	+ 81.0	+ 21.6
5	82/4	260.0	325.0	+ 65.0	+ 25.0
6	59/1	432.0	534.0	+ 102.0	+ 23.6
6	59/9	432.0	551.0	+ 119.0	+ 27.6
6	59/10	447.0	542.0	+ 95.0	+ 21.3
6	62/3	480.0	601.0	+ 121.0	+ 25.2
6	62/4	508.0	633.0	+ 125.0	+ 24.6
6	62/6	566.0	676.0	+ 110.0	+ 19.4
7	73/2	420.0	489.0	+ 69.0	+ 16.4
7	87/5	382.0	442.0	+ 60.0	+ 15.7
7	97/6	540.0	626.0	+ 86.0	+ 15.9
7	103/1	529.0	622.0	+ 93.0	+ 17.6
7	103/2	503.0	588.0	+ 85.0	+ 16.9
7	103/3	512.0	616.0	+ 104.0	+ 20.3
8	74/1	486.0	540.0	+ 54.0	+ 11.1
8	74/4	406.0	480.0	+ 74.0	+ 18.2
8	86/6	594.0	665.0	+ 71.0	+ 12.0
8	89/3	536.0	620.0	+ 84.0	+ 15.7
8	151/2	383.3	459.9	+ 76.6	+ 20.0
8	151/3	383.3	416.1	+ 32.8	+ 8.6
9	60/3	436.0	503.0	+ 67.0	+ 15.4
9	60/8	436.0	506.0	+ 70.0	[illegible]
9	60/11	508.0	597.0	[illegible]	[illegible]
9	62/1	499.0	519.0	[illegible]	[illegible]





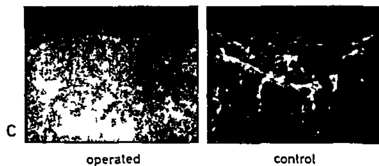


Fig 5

L L L S_1 S must be sectioned so that the hind extremity in rabbit will to the greatest extent be motor denervated (KRAUSE 1868, CRAIGIE 1948) However for this an extensive exposure of the spinal cord is required the author therefore chose to section only the L_7 S S_2 roots which for the mentioned topographical reason can be reached with a relatively much smaller operation A sectioning of these three roots according to TROUPP (1961) results in a definite paresis which renders the extremity unusable

Denervation (Group B)

The animals here were anaesthetized in the same way as at the experiments with previous groups A dorsal midline incision exposed the lumbar spine *and adjacent parts of the sacrum right sided hemilaminectomy of* L *and* L_7 and unroofing of the proximal part of the sacral canal were then performed One of the biggest problems was the extensive bleeding that ensued but this could to a large extent be checked by the hindquarters of the animal being raised from the base thus accentuating the lordosis and reducing the pressure from the abdominal side (TROUPP 1965) In certain instances Oxycel (Parke Davis) had to be applied to the bleeding bony surfaces to ensure satisfactory haemostasis

The three spinal nerves L S S_2 on the right side were lifted up by means of loose ligatures After the dura had been opened the anterior roots of the nerves were sectioned The wound was sprayed with Polybacin (Astra) and then sutured in two layers with perlon

The growth conditions in the proximal tibiae were studied post-operatively after tetracycline labelling Useful data were obtained from 18 animals arranged in groups of 6 (Table 6)

The noradrenalin content in the autonomic innervation apparatus of the intramedullary (tibiae) blood vessels was also examined in these 18 animals with the aid of the fluorescence method

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Fig 5 Fluorescent microphotographs Peripheral nerve section 6th postoperative day Oxytetracycline labelling discloses the accelerated longitudinal growth in the proximal tibial metaphysis on operated side compared with control side after right sided femoral and sciatic nerve sectioning (A) No such effect can be seen after corresponding sham operation (B) Whole mount preparations of tibial intramedullary arteries treated with formaldehyde are depicted in C The vessel from the operated side shows a total lack of specific fluorescence in contrast to the vessel from the control side where a network of fluorescent terminal nerve fibres can be seen. Magnification A B 76× C 190×

Table 6 Group B Longitudinal growth in the proximal tibia in rabbit after sectioning of three anterior nerve roots (L_7-S_1 S_2)

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in % of non-op side
3	226 1	318 0	335 0	+ 17 0	+ 5 4
3	226 2	383 0	441 0	+ 58 0	+ 15 1
3	226 6	329 0	361 0	+ 32 0	+ 9 7
3	227 1	383 0	416 0	+ 33 0	+ 8 6
3	227 2	383 0	394 0	+ 11 0	+ 2 9
3	229 2	405 0	445 0	+ 40 0	+ 9 9
6	222 4	380 0	493 0	+ 113 0	+ 29 7
6	222 5	372 0	438 0	+ 66 0	+ 17 7
6	225 1	405 0	493 0	+ 88 0	+ 21 7
6	225 2	438 0	530 0	+ 92 0	+ 21 0
6	225 4	438 0	537 0	+ 99 0	+ 22 6
6	225 6	438 0	542 0	+ 104 0	+ 23 7
9	158 5	449 0	525 6	+ 76 6	+ 17 1
9	222 1	383 0	493 0	+ 110 0	+ 28 7
9	222/2	438 0	493 0	+ 55 0	+ 12 6
9	227 6	383 0	452 0	+ 69 0	+ 18 0
9	229 3	361 0	438 0	+ 77 0	+ 21 3
9	229/14	380 0	427 0	+ 47 0	+ 12 4

Sham operation (Group B sham)

With the animals under anaesthesia as mentioned the vertebral canal was exposed and opened as described above The spinal nerves involved were lifted up and the dura was opened This procedure was carried out with the utmost care in order to avoid trauma to the nerve fibres The nerve roots were otherwise completely untouched and the wound was sutured as in the previous group

However a number of animals post-operatively showed various degrees of paresis in the right hind leg these were excluded from the material which included only those where the motility in the hind extremities seemed of equal value

The longitudinal bone growth in the proximal tibiae was observed post operatively after tetracycline labelling in 18 animals (Table 7)

Results

Sectioning of the three anterior nerve roots caused a degree of paresis that prevented the animal from using the denervated limb This was dragged

Table 7 (Group B-sham) Longitudinal grow th in the proximal tibia in rabbit after sham-operation (sectioning of three nerve roots)

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in of non-op side
3	232/2	482 0	482 0	0 0	0 0
3	232/3	466.5	462 1	− 4 4	− 0 9
3	235/1	460 0	460 0	0 0	0 0
3	235/3	526 0	526 0	0 0	0 0
3	235/4	515 0	526 0	+ 11 0	+ 2 1
3	241/3	449 0	449 0	0 0	0 0
6	231/3	383 0	383 0	0 0	0 0
6	231/2	526 0	518 0	− 8 0	− 1 5
6	233/1	481 8	481 8	0 0	0 0
6	233/2	515 0	507 0	− 8 0	− 1 6
6	234/1	449 0	449 0	0 0	0 0
6	234/4	493 0	493 0	0 0	0 0
9	231/5	449 0	449 0	0 0	0 0
9	231/6	383 0	383 0	0 0	0 0
9	233/3	504 0	504 0	0 0	0 0
9	233/4	493 0	493 0	0 0	0 0
9	233 6	493 0	493 0	0 0	0 0
9	231/6	471 0	471 0	0 0	0 0

after the body in a manner similar to that after peripheral nerve sectioning and often showed an oedema distally An increasing muscular atrophy was noted during the observation time

The sham-operated animals showed the same degree of activity in both hind extremities

The longitudinal *growth in the proximal parts of the tibiae was studied*

Table 8 (Group B) The effect of sectioning of three anterior nerve roots (L_7-S_1 S_2) on *the longitudinal growth in the proximal tibial metaphysis in rabbit*

Days after operation	*Observed length difference* in of the control side Arithmetic mean ± 2 79	The effect ≠ 0 Significances (2-sided t tests)
3	+ 8 6	***[1]
6	+ 22 7	***
9	+ 18 4	* [1]

[1] The effect *during the 3rd and the 9th day differs from the effect* during the 6th day with the significance *** and * respectively at one sided as well as at two-sided t tests

Table 9 Group B-sham: *The effect of sham-operation (sectioning of three nerve roots) on the longitudinal growth in the proximal tibial metaphysis in rabbit,*

Days after operation	Observed length difference in % of the control side *Arithmetic mean ± 1 09*	The effect ≠ 0 Significances *(2 sided t tests)*
3	− 0.2	—
6	− 0.5	—
9	0 0[1]	no analysis possible

[1] Mean value cannot be given.

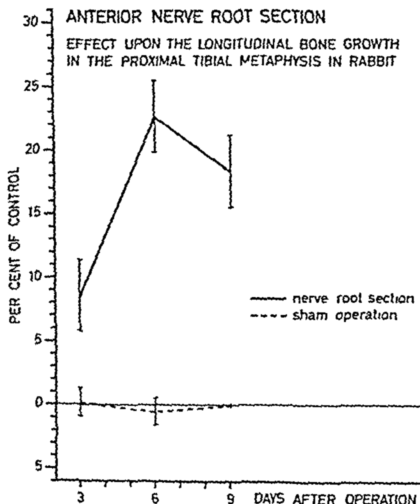


Fig 6

during the third, the sixth and the ninth post-operative day because the most marked changes in growth after peripheral nerve sectioning (Group A) were observed during this very period. Tables 6 and 7 show the differences in longitudinal growth in the two bones. The difference is given in percentage of the non-operated control side.

The arithmetic means of the percentage differences of each subgroup of 6 animals are collated in Tables 8 and 9 which report the degree of significance in the differences between operated and non-operated side. The results are presented graphically in Fig. 6.

Table 8 shows that the longitudinal growth in the proximal tibia after unilateral sectioning of the anterior nerve roots L S S (Group B) is greater on the operated side than on the non-operated; this is highly significant. *The most accelerated growth is demonstrated during the sixth post-operative day* when a difference of more than 20 % between the two sides is found. Highly significant and probably significant lower values, respectively, are noted during the third and the ninth days.

The effects of the sham-operation (Group B-sham) are quite insignificant (Table 9).

The statistical analysis shows that the effects in Group B are greater than those in Group B-sham with *** significance.

Intramedullary blood vessels from all 18 animals in Group B show uniform noradrenalin fluorescence in both denervated and non-denervated tibia.

3. Sectioning of three posterior nerve roots

With the same motivation as in the previous section the posterior nerve roots L S S were chosen for sectioning.

Denervation (Group C)

The same technique for exposing the spinal nerves was used for this group as for Group B (see above) with the same kind of anaesthesia. After the dura had been opened the mentioned posterior roots on the right side were sectioned proximal to the spinal ganglion. Spraying with Polybacin and suture were as above.

The longitudinal bone growth in the proximal tibial metaphyses was measured after tetracycline labelling.

The occurrence of fluorescent noradrenalin product *in the autonomic groundplexus of the intramedullary (tibia) vessels* was checked on both *operated and non-operated side*.

Useful data were obtained from 18 animals in this group (Table 10).

* The 99.9 % confidence intervals of the subgroups B 3 and B-sham 3, B 6 and B-sham 6, and B 9 and B-sham 9 do not overlap.

Table 10 (Group C) Longitudinal growth in the proximal tibia in rabbit after sectioning of three posterior nerve roots (L_7 S_1 S_2)

Days after operation	Animal	Non operated side (μ)	Operated side (μ)	Difference op — non op side (μ)	Difference in % of non-op side
3	236/?	481.8	492.8	+ 11.0	+ 2.3
3	241/6	383.3	405.2	+ 21.9	+ 5.7
3	246/1	525.6	536.6	+ 11.0	+ 2.1
3	246/?	438.0	427.0	− 11.0	− 2.5
3	246/6	438.0	449.0	+ 11.0	+ 2.5
3	246/13	438.0	438.0	0.0	0.0
6	230/1	372.0	372.0	0.0	0.0
6	230/2	427.0	438.0	+ 11.0	+ 2.6
6	230/3	372.0	378.0	+ 6.0	+ 1.6
6	230/4	372.0	383.0	+ 11.0	+ 3.0
6	230/5	340.0	372.0	+ 32.0	+ 9.4
6	230/6	383.0	383.0	0.0	0.0
9	241/12	460.0	460.0	0.0	0.0
9	242/3	492.8	492.8	0.0	0.0
9	242/12	503.7	503.7	0.0	0.0
9	244/1	400.8	399.7	− 1.1	− 0.3
9	244/2	405.2	405.2	0.0	0.0
9	244/13	481.8	481.8	0.0	0.0

Sham operation (Group B sham)

Because this operation is identical with the sham operation reported under 2 b this animal group (Group B sham Table 7) was used as comparison material also for this experimental series

Results

After unilateral sensory root sectioning no positive side difference could be observed post operatively regarding the motility in the hind limbs when the animals were allowed freedom of movement However when held up by the nape the animals showed the same phenomenon as reported by Troupp (1961) a tendency for the denervated extremity to sink downwards possibly an expression of non response by the positional sense No positive muscular atrophy could be noted

The differences in growth in length in the proximal tibiae in denervated (Group C) and in sham operated (Group B sham) animals were measured with the tetracycline method—shown in Tables 10 and 7 respectively The observations were made during the third sixth and ninth post operative

Table 11 (Group C) The effect of sectioning of three posterior nerve roots (L_7 S_1 S_2) on the longitudinal growth in the proximal tibial metaphysis in rabbit

Days after operation	Observed length difference in of the control side Arithmetic mean	The effect ≠ 0 Significances (2 sided t tests)
3	+ 1 7 ± 2 79	—
6	+ 2 8 ± 2 79	*
9	0 0 ± 0 13[1]	—

[1] Individual analysis 5 degrees of freedom

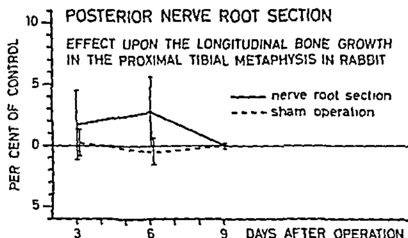


Fig 7

days and as earlier the differences are reported in percentage of non-operated control side

The arithmetic means of each subgroup are shown in Tables 11 and 9 where the significance levels of the differences are also given The results are presented graphically in Fig 7

Table 11 shows that the observed effect during the sixth post-operative day is on the verge of being non significant

At comparison of the subgroups in Group C and Group B sham no significant difference could be established

The tibial intramedullary blood vessels from the denervated as well as from the normal extremity show no differences in the amount of *trans mitter* substance at fluorescence microscopy

The effects in Group B-sham are not significant.

The lumbosacral sympathetic trunks in rabbit are situated between the dorsal body wall and the abdominal aorta as well as between the dorsal body wall and the median sacral artery The lumbar parts are situated close together and each contains seven ganglions The ganglions on the two sides are separated only by the lumbar vessels The sacral parts include four ganglions situated next to corresponding sacral foramina Here on the ventral surface of the sacrum the ganglions of the two sides are well separated The left sympathetic trunk is easier to reach (KRAUSE 1868, CRAIGIE 1948)

The author has found only one piece of information (GOETZ *et al* 1955) regarding the postganglionic outflow from the sympathetic trunk to the lower limb in rabbit These authors state that because the lowest post ganglionic outflow comes from the L_5 or the L_6 ganglion the 4th—6th lumbar ganglions should be removed so that the postganglionic connexions to the lumbosacral plexus (L to S) will be severed

At preliminary experiments attempts were made to verify this statement, left sided resection of the 4th 5th and 6th sympathetic lumbar ganglion was performed on 6 animals (for technical details see below) Later investigation of tibial intramedullary vessels with the aid of the fluorescence method of FALCK & HILLARP showed in no instances signs of postganglionic denervation of these structures Arteries from both operated and non operated side showed a fluorescent network of similar appearance

Left sided ganglionectomies of varying extent were next carried out between the levels L and S_2 on 11 animals The results are reported in Table 12 They indicate that the lowest postganglionic outflow to the medullary cavity in the rabbit tibia occurs from the S ganglion To obtain complete postganglionic denervation of the medullary vessels the ganglions between the L and S_2 levels must be removed

Sympathetic lumbosacral ganglionectomy (Group D)

Under the usual Mebumal ether anaesthesia, the abdomen was opened by a midline incision The abdominal viscera was moved over to the right side and after the abdominal aorta and the inferior vena cava had also been carefully moved in the same direction the sympathetic trunks could be exposed between the medial borders of the psoas muscles The ganglions L I L_7, S S_4 on the left side were removed and *after spraying with* Poly-bacin, the abdomen was sutured in two layers with perlon

[8] Here as in the following intervening parts of the sympathetic chain have also been removed

Table 12 The occurrence of fluorescent noradrenalin product in tibial intramedullary arteries after sympathectic ganglionectomy of varying extent (+ indicates the presence and — the absence of fluorescence)

L_4	+
L_4—L_5	+
L_4—L_6	+
L_6—L_7	+
L_6—S_1	+
L_4—S_2	—
L_5—S_2	—
L_6—S_2	+[1]
L_7—S_2	—[1]
S_1—S_2	+
S_2	+

[1] The irregular localizations of intermediate ganglia in the lumbar region of rabbit (WRETE 1911) could cause the varying occurrence of fluorescence in these cases

The growth conditions were studied post-operatively in the proximal tibiae after tetracycline labelling Because earlier literature gives highly divergent information about the duration of a possible circulatory effect by the operation the observations were extended over a period of 18 days (Table 13)

In all instances the noradrenalin content was examined in the autonomic groundplexus of the tibial intramedullary arteries with the aid of the fluorescence method

Useful data were obtained from 36 animals

Sham operation (Group D sham)

With the animals anaesthetized as reported above the abdomen was opened in a similar manner the sympathetic trunks were exposed by careful dissection but otherwise left intact and the abdomen was sutured after Polybactin spraying

After tetracycline labelling the longitudinal bone growth was studied in 18 animals (Table 14)

Results

No external differences between the hind limbs could be observed and except for the first post-operative day the animals in both experimental groups were normally agile.

The observed longitudinal growth in the proximal tibiae in both groups

Table 13 Group D Longitudinal growth in the proximal tibia in rabbit after sympathetic lumbosacral ganglionectomy (ganglion L_5 L_6 L_7 S_1 S_2)

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in % of non-op side
3	171	317.6	295.7	−21.9	−6.9
3	177 5	293.5	277.0	−16.5	−5.6
3	216 1	328.5	328.5	0.0	0.0
3	216 2	328.5	328.5	0.0	0.0
3	216 3	350.4	350.4	0.0	0.0
3	220 1	391.0	394.0	+ 3.0	+0.8
6	187 1	372.3	372.3	0.0	0.0
6	214 2	427.0	438.0	+11.0	+2.6
6	214 3	438.0	438.0	0.0	0.0
6	215 14	526.0	493.0	−33.0	−6.3
6	215 15	504.0	482.0	−22.0	−4.4
6	216 4	441.0	449.0	+ 8.0	+1.8
9	193 4	401.9	434.7	+32.8	+8.2
9	215 3	482.0	482.0	0.0	0.0
9	215 4	468.0	449.0	−19.0	−4.1
9	215 5	457.0	449.0	− 8.0	−1.8
9	221/1	493.0	493.0	0.0	0.0
9	221 2	449.0	438.0	−11.0	−2.5
12	183 4	405.2	405.2	0.0	0.0
12	196/12	503.7	503.7	0.0	0.0
12	200 2	441.3	449.0	+ 7.7	+1.8
12	213 4	485.0	471.0	−14.0	−2.9
12	213 5	450.0	471.0	−21.0	−4.7
12	218 5	383.0	383.0	0.0	0.0
15	185 6	339.5	339.5	0.0	0.0
15	185 12	416.1	410.6	− 5.5	−1.3
15	213 6	449.0	452.0	+ 3.0	+0.7
15	213 12	438.0	438.0	0.0	0.0
15	219 4	449.0	449.0	0.0	0.0
15	219 5	438.0	449.0	−11.0	+2.5
18	186 12	438.0	434.7	− 3.3	−0.8
18	203	438.0	449.0	−11.0	+2.5
18	206	438.0	438.0	0.0	0.0
18	232	438.0	441.0	− 3.0	+0.7
18	223 4	438.0	442.0	+ 4.0	+0.9
18	223 5	464.0	460.0	− 4.0	−0.9

Table 14 (Group D sham) Longitudinal growth in the proximal tibia in rabbit after sham-operation (sympathetic lumbosacral ganglionectomy)

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in % of non-op side
3	212/2	394.2	394.2	0.0	0.0
3	212/3	416.1	416.1	0.0	0.0
3	212/4	339.5	339.[illegible]	0.0	0.0
3	217/5	370.8	317.6	− 3.2	− 1.0
3	217/1	359.0	372.0	+ 13.0	3.6
3	229/6	343.0	344.0	− 1.0	− 0.3
6	211/3	356.2	334.0	2.2	− 0.7
6	211/6	355.4	355.4	0.0	0.0
6	212/1	355.4	355.4	0.0	0.0
6	217/3	405.0	405.0	0.0	0.0
6	217/5	405.0	40[illegible].0	0.0	0.0
6	217/6	460.0	460.0	0.0	0.0
9	217/12	471.0	471.0	0.0	0.0
9	217/13	482.0	471.0	− 11.0	− 2.3
9	221/6	471.0	471.0	0.0	0.0
9	228/3	375.0	372.0	− 3.0	− 0.8
9	229/12	438.0	438.0	0.0	0.0
9	229/13	438.0	438.0	0.0	0.0

is reported in Tables 13 and 14 and as earlier the differences are given in percentage of the non-operated control side (right)

Tables 15 and 16 show besides the arithmetic means of the percentage differences of each subgroup also the level of significance of the differences between operated and non-operated side The results are presented graphically in Fig 8

Sympathetic lumbosacral ganglionectomy gives no significant effects (5 % level) during the first 18 post-operative days on longitudinal growth according to Table 15 nor does the corresponding sham operation (Table 16)

The investigation of the tibial intramedullary arteries in Group D shows in all instances a total lack of fluorescence in the autonomic groundplexus of the arteries on the left ganglionectomized side whereas corresponding vessels on the right (control) side show a completely normal picture (cf Fig 2 on page 41)

5 Immobilization with intact innervation

To produce partial inactivation without affecting the innervation apparatus sectioning and resection (about 1 cm) of the Achilles tendon were

Table 13 (Group D) Longitudinal growth in the proximal tibia in rabbit after sympathetic lumbosacral ganglionectomy (ganglion L_5 L_6 L S_1 S)

Days after operation	Animal	Non operated side (μ)	Operated side (μ)	Difference op — non op side (μ)	Difference in of non op side
3	177/1	317 6	295 7	− 21 9	− 6 9
3	177/5	293 5	277 0	− 16 5	− 5 6
3	216/1	328 5	328 5	0 0	0 0
3	216/2	378 5	378 5	0 0	0 0
3	216/3	350 4	350 4	0 0	0 0
3	220/1	391 0	394 0	+ 3 0	+ 0 8
6	182/1	372 3	372 3	0 0	0 0
6	214/2	427 0	438 0	+ 11 0	+ 2 6
6	214/3	438 0	438 0	0 0	0 0
6	215/14	526 0	493 0	− 33 0	− 6 3
6	215/15	504 0	482 0	− 22 0	− 4 4
6	216/4	441 0	449 0	+ 8 0	+ 1 8
9	193/4	401 9	434 7	+ 32 8	+ 8 2
9	215/3	482 0	482 0	0 0	0 0
9	215/4	468 0	449 0	− 19 0	− 4 1
9	215/5	457 0	449 0	− 8 0	− 1 8
9	221/1	493 0	493 0	0 0	0 0
9	221/2	449 0	438 0	− 11 0	− 2 5
12	183/4	405 2	405 2	0 0	0 0
12	196/12	503 7	503 7	0 0	0 0
12	200/2	441 3	449 0	+ 7 7	+ 1 8
12	213/4	485 0	471 0	− 14 0	− 2 9
12	213/5	450 0	471 0	− 21 0	− 4 7
12	218/5	383 0	383 0	0 0	0 0
15	185/6	339 5	339 5	0 0	0 0
15	185/12	416 1	410 6	− 5 5	− 1 3
15	213/6	449 0	452 0	+ 3 0	+ 0 7
15	213/12	438 0	438 0	0 0	0 0
15	219/4	449 0	449 0	0 0	0 0
15	219/5	438 0	449 0	+ 11 0	+ 2 5
18	186/12	438 0	434 7	− 3 3	− 0 8
18	220/3	438 0	449 0	+ 11 0	+ 2 5
18	220/6	438 0	438 0	0 0	0 0
18	223/[illegible]	438 0	441 0	+ 3 0	+ 0 7
18	223/4	438 0	442 0	+ 4 0	+ 0 9
18	223/5	464 0	460 0	− 4 0	− 0 9

chosen Merely sectioning of the tendon has been found to be insufficient because a good function was again established within one week (cf GEISER & TRUETA 1958)

Partial resection of the Achilles tendon (Group F)

The animals were anaesthetized in the usual way with Mebumal ether After skin incision the sheath round the triceps surae tendon on the right side was opened and about 1 cm of the tendon was resected just proximal to its insertion on calcaneus The skin was sutured

Because earlier investigations (GEISER & TRUETA 1958 LANDRY & FLEISCH 1964) have shown that despite resection scar healing of the tendon can occur with returning function of the gastrocnemius muscle after two or three weeks the observation period for this experimental group was extended to 18 days

The growth conditions in the proximal tibiae were studied at the appropriate post-operative period after tetracycline labelling in 36 animals (Table 17)

Sham operation (Group E sham)

This operation was performed in exactly the same way as the previous ones except for the sectioning and the resection of the Achilles tendon which was left untouched after being exposed by a 1 cm long incision in its sheath

The skeletal growth in 18 animals thus treated was studied in the usual manner with the tetracycline method (Table 18)

Results

The tendon resection caused a considerable inactivation of the limb involved during the first ten to twelve post operative days The paw was kept dorsally flexed and the hind leg was not used when the animal moved No extension contracture of the ankle joint (HULTH & OLERUD 1960) could be observed Towards the end of the second week the animal usually began to use the tenotomized limb without however the mobility being altogether normalized during the eighteen days involved Post mortem examination showed in most instances a fibrous cicatrization between the two ends of the severed tendon and also various degrees of muscular atrophy mainly in the gastrocnemius muscle

No effect of the sham operation could be observed after the first post operative day

Tables 17 and 18 show the longitudinal growth in the proximal tibial metaphyses of the two experimental groups and the differences are given

Table 17 (Group E Longitudinal growth in the proximal tibia in rabbit after sectioning and partial resection of the Achilles tendon.

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in % of non-op side
3	70 1	534.0	579.0	+ 45.0	+ 8.4
3	70 2	486.0	536.0	+ 50.0	+ 10.3
3	114 1	572.0	648.0	+ 76.0	+ 13.3
3	114 3	518.0	605.0	+ 87.0	+ 16.8
3	129 5	484.0	555.0	+ 71.0	+ 14.7
3	202 6	394.2	438.0	+ 43.8	+ 11.1
6	69 3	596.0	665.0	+ 69.0	+ 11.6
6	91 1	389.0	432.0	+ 43.0	+ 11.1
6	91 2	475.0	553.0	+ 78.0	+ 16.4
6	113 6	475.0	562.0	+ 87.0	+ 18.3
6	170 6	481.8	547.5	+ 65.7	+ 13.6
6	174 1	438.0	514.7	+ 76.7	+ 17.5
9	71 1	531.0	553.0	+ 22.0	+ 4.1
9	71 2	505.0	540.0	+ 35.0	+ 6.9
9	71 3	644.0	663.0	+ 19.0	+ 3.0
9	91 5	339.0	352.0	+ 13.0	+ 3.8
9	91 6	529.0	555.0	+ 26.0	+ 4.9
9	91 13	512.0	557.0	+ 45.0	+ 8.8
12	104/1	583.0	590.0	+ 7.0	+ 1.2
12	104 2	594.0	594.0	0.0	0.0
12	104 3	620.0	637.0	+ 17.0	+ 2.7
12	112/3	562.0	605.0	+ 43.0	+ 7.7
12	112 5	553.0	583.0	+ 30.0	+ 5.4
12	167 14	459.9	492.8	+ 32.9	+ 7.2
15	106 4	475.0	454.0	− 21.0	− 4.4
15	106 5	562.0	583.0	+ 21.0	+ 3.7
15	106 12	475.0	518.0	+ 43.0	+ 9.1
15	113 1	570.0	583.0	+ 13.0	+ 2.3
15	166 3	394.2	423.8	+ 29.6	+ 7.5
15	166 4	383.3	394.2	+ 10.9	+ 2.8
18	104 4	583.0	583.0	0.0	0.0
18	104 5	562.0	562.0	0.0	0.0
18	104 6	562.0	562.0	0.0	0.0
18	104 1	583.0	594.0	+ 11.0	+ 1.9
18	113 3	562.0	562.0	0.0	0.0
18	164	449.0	449.0	0.0	0.0

Table 18 (Group E-sham) Longitudinal growth in the proximal tibia in rabbit after sham-operation (sectioning and partial resection of the Achilles tendon)

Days after operation	Animal	Non-operated side (μ)	Operated side (μ)	Difference op — non-op side (μ)	Difference in % of non-op side
3	138/5	383.3	383.3	0.0	0.0
3	142/4	383.3	383.3	0.0	0.0
3	142/5	383.3	383.3	0.0	0.0
3	148/2	339.5	339.5	0.0	0.0
3	202/12	459.9	462.1	+ 2.2	+ 0.5
3	206/1	449.0	449.0	0.0	0.0
6	142/1	427.1	427.1	0.0	0.0
6	142/2	416.1	416.1	0.0	0.0
6	142/3	459.9	459.9	0.0	0.0
6	169/5	514.7	503.7	− 11.0	− 2.1
6	169/6	470.9	468.7	− 2.2	− 0.5
6	169/12	533.3	536.6	+ 3.3	+ 0.6
9	167/3	438.0	438.0	0.0	0.0
9	167/4	394.2	392.0	− 2.2	− 0.6
9	168/2	449.0	449.0	0.0	0.0
9	169/2	492.8	492.8	0.0	0.0
9	169/3	492.8	492.8	0.0	0.0
9	170/2	479.6	480.7	+ 1.1	+ 0.2

in the same way as earlier in percentage of the non-operated control side.

The arithmetic means of the percentage growth differences in each subgroup are collated in Tables 19 and 20, which also show the levels of significance of the differences between operated and non-operated side.

The results are presented graphically in Fig. 9.

Table 19 (Group E) shows that the longitudinal growth in the proximal tibial metaphysis on the tenotomized side is (highly significant) more rapid during a limited post-operative period than the growth in the corresponding region on the control side. Maximum growth difference is observed during the sixth post-operative day with lower values (highly significant—two-sided t test) during the third and the ninth day. An equalization of the differences occurs gradually. During the eighteenth post-operative day the difference between operated and non-operated side does not differ significantly from zero.

The effects of the sham-operation (Group E sham) are not significant (Table 20).

The statistical analysis indicates that the effects in Group E are significantly greater than those in Group E sham.

The 99.9 % confidence intervals of the subgroups E 3 and E sham 3, E 6 and E sham 6, and E 9 and E sham 9 do not overlap.

Table 19 (Group E The effect of partial resection of the Achilles tendon on the longitudinal growth in the proximal tibial metaphysis in rabbit

Days after operation	Observed length difference in of the control side Arithmetic mean	The effect ≠ 0 Significances (2-sided t tests)
3	− 12.4 ± 2.79	***1
6	− 14.8 ± 2.79	***
9	− 5.2 ± 2.79	***1
12	− 4.0 ± 2.79	**
15	− 3.5 ± 2.79	*
18	+ 0.3 ± 0.81[2]	—

[1] The analysis shows that the effect during the 3rd and the 9th day differs from the effect during the 6th day with the significance * and *** respectively at the one sided t test, and the significance — and *** respectively at the two-sided t test.
[2] Individual analysis, 5 degrees of freedom

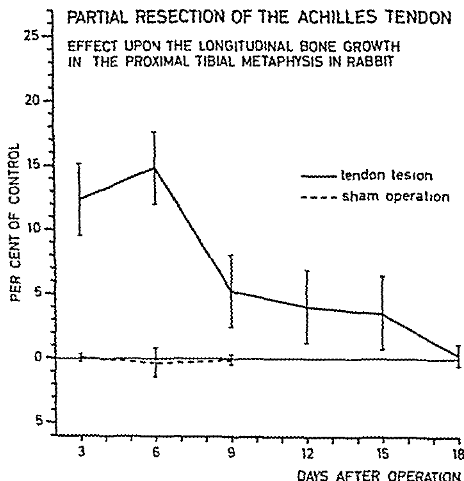


Fig 9

Table 20 (Group E-sham) The effect of sham-operation (partial resection of the Achilles tendon) on the longitudinal growth in the proximal tibial metaphysis in rabbit

Days after operation	Observed length difference in of the control side Arithmetic mean	The effect ≠ 0 Significances (2-sided t tests)
3	+ 0 1 ± 0 22[1]	—
6	− 0 3 ± 1 09	—
9	− 0 1 ± 0 29[1]	—

[1] Individual analysis 5 degrees of freedom

G SUMMARY

The endochondral growth from the proximal growth plate of the diaphysis towards the metaphysis in growing rabbit tibia was studied with the aid of tetracycline labelling at disturbance of various nervous functions and at partial immobilization with intact innervation

The results indicate that a *peripheral nerve sectioning* causes a brief (highly significant) initial acceleration of the longitudinal growth in the investigated region Maximum effect is achieved during the sixth post operative day thereafter the growth stimulation decreases and during the eighteenth post-operative day a retarded growth in length (probably signif icant) occurs on the operated side

A *partial motor denervation* of the lower extremity by *sectioning three* anterior nerve roots also results in a changed growth rate The maximum noted growth acceleration occurs at the same time point as after peripheral nerve sectioning i e during the sixth post-operative day

Sectioning of corresponding *posterior nerve roots* causes no positive change in the growth in skeletal length

In the three mentioned experimental groups the *vascular nerve supply* in the region involved was also studied Tibial intramedullary arteries were thus investigated regarding the occurrence of fluorescent noradrenalin product in their adrenergic nerves The results indicate that peripheral nerve sectioning also includes a postganglionic sympathetic denervation in the investigated skeletal region whereas no such effect could be observed after motor as well as sensory root sectioning

The *normal postganglionic sympathetic connexions* to the intramedullary arteries of the tibia were investigated with the aid of the same fluorescence method and guided by these results an animal group was *subjected to lumbosacral sympathectomy* No significant effect on the longitudinal growth could be observed

To judge by the investigations partial immobilization by *sectioning and resection of the Achilles tendon* accelerates the longitudinal bone growth of the proximal tibia for a short period During the sixth post-operative day, the effect of the operation reaches its maximum as occurs after peripheral nerve sectioning and after motor root sectioning

Chapter 2 Intra-osseous blood flow and its relation to accelerated skeletal growth

I *Earlier investigations*

An increased blood flow to the growth zones of a long bone has for a long time been postulated as being one of the most essential factors for stimulating skeletal growth The object of most growth stimulating procedures has therefore been to try to influence the haemodynamics in bone so as to increase the blood supply to the cartilaginous plates As mentioned earlier considerable uncertainty still prevails about the mechanism underlying the increased bone growth and it has never been made clear whether or in what manner the intra osseous circulation is changed in skeletal parts that have shown accelerated growth

After a survey of the vascular anatomy of a long bone a report follows of the various measurement methods applied to skeletal blood flow and the present concept of bone circulation according to skeletal blood flow measurements

A THE VASCULAR ANATOMY OF A LONG BONE

LANGER (1876) was the first to demonstrate the essential arterial inflows as well as their intra-osseous ramifications that supply a long bone These investigations concerned femur and tibia in *homo* Since then numerous works have been published concerning the morphology of the intra-osseous vessels in various species

Thus the investigation in *homo* was carried out also by *inter al* LEXER *et al* (1904) TRUETA & HARRISON (1953) LAING (1953) SUSSE (1955 1956) HULTH (1956) STEINBACH *et al* (1957) HARALDSSON (1959) TRUETA & MORGAN (1960) BROOKES *et al* (1961) on calf and cow TILLING (1958) on dog *inter al*, DRINKER *et al* (1922) MARNEFFE (1951) PETERSON *et al* (1957) GAJO *et al* (1963) on rabbit *inter al* DOAN (1922) MARNEFFE (1951) BROOKES & HARRISON (1957), BRANEMARK (1959) GOTHMAN (1960) TRUETA & AMATO (1960) TRUETA & MORGAN (1960) ZUCHMAN (1960) LISKOVA & HERT (1961) GAJO *et al* (1963) TRUETA & CAVADIAS (1964) on rat *inter al* BROOKES (1958 1965) IRVING (1964) ABDALLA & HARRISON (1966)

Various forms of injection technique as well as angiography and vital microscopy have been used and by experimentally eliminating one or more of the inflow channels attempts have been made to establish the individual importance of these for the skeletal blood supply Many of the investigations were made on rabbit tibia, but no fundamental differences appeared to exist between different long bones or between different species (TRUETA & MORGAN 1960)

When the reports of the various investigators are summarized the following general main lines appear for the vascular pattern of a long bone

Arteria nutritia besides a main nutrient artery there can occur a varying number of accessory nutrient arteries which after entry into the medullary cavity mainly ramify in the periphery of the bone medulla, thus subcortically During the course to the metaphyses a rich amount of branches are given off partly to the medullary tissue where a dense capillary network is formed by extensive anastomosis partly also to the cortex Disagreement prevails however concerning the vascularization of the cortical tissue of the diaphysis Whereas many investigators state that this takes place both from medullary and from periosteal vessels there are others who are of the opinion that periosteal vessels normally contribute with insignificant or no blood whatever to underlying bone

In the metaphyses the terminal nutritional ramifications anastomose with metaphysial arteries Long hairpin shaped capillary loops supply the metaphysial side of the growth plate in the growing individual in such a manner that branches from arteria nutritia are responsible for the central 4/5 and metaphysial arteries for the remaining peripheral part

Periosteal vessels the periosteum especially in a growing individual is considerably vascularized Thus several large arteries are found running longitudinally along the bone After extensive ramifying and anastomozing they form a dense network of vessels that cover the periosteum However this network is also connected with intramuscular arteries The periosteal network particularly in the metaphysial regions establishes a profuse amount of connexions with cortical vascular structures

At both ends of a long bone anastomoses of the coarse periosteal arteries occur in such a manner that two circular rings of vessels are formed wherein branches from the larger soft part arteries around the joints are also included The larger of the two rings of vessels are found level with the joint line and branches from this condition the epiphysial arteries The smaller is situated on the border between growth plate and metaphysis and contributes coarse vessels which as metaphysial arteries penetrate the cortex From anastomoses between the two rings of vessels the circumferential artery of the growth plate also emanates

The epiphysial arteries find a way into the epiphysis immediately next to the capsular attachment and after abundant ramifying and anastomosing terminal ramifications contact the epiphysial side of the growth plate No difference between central and peripheral parts such as is found on the metaphysial side has been observed here

The metaphysial arteries divide after passing through the cortex into increasingly fine branches that anastomose with the ramifications from arteria nutritia and contribute to the blood supply of the growth plate in the manner mentioned

Considerable disagreement has existed concerning the occurrence of vascular connexions between epiphysis and metaphysis through the cartilaginous growth plate It seems that only exceptionally have these been observed (*When however the growth has ceased vessels might cross the scar thus* establishing endosteal anastomoses between the two vascular beds) Extensive extra-osseous connexions however exist via the described anastomosing ring formations of vessels This external anastomosis is most obvious in the adult

The *venous* blood in the marrow of a long bone collects in structures known as sinusoids In the metaphysial regions these have a vertical course which *towards the middle of the shaft is increasingly transversal* The sinusoids in the diaphyseal medulla gradually drain into coarser vessels which fan shaped flow together into a usually single central venous channel A vena nutritia can be regarded as a branch of this structure

The endosteal parts of the diaphyseal cortex drain their blood into medullary sinusoids or collection veins whereas the external parts are drained through periosteal veins There are also venous connexions that directly link together the medullary cavity with the outer surface of the bone They are rather few in the middle of the shaft but extremely profuse *in the metaphysial regions*

Sinusoids of a similar type as in the medullary cavity of the diaphysis are found in the epiphyses They are more irregular however in their distribution The venous collecting vessels that sometimes flow together to a central channel drain their contents into veins chiefly corresponding to the arteries but also often directly into large thin walled vessels that pass the cortex establishing connexion with surrounding soft part veins in a way similar to that in the metaphysial regions

Only the larger extra-osseous veins are furnished with valves These can often be found precisely at the exit through the cortex

It can be said *in conclusion that a long* bone gets its arterial supply from

several directions where arteria nutritia is only the largest inflow passage. Especially at the two ends of the bone the relation with arterial structures in surrounding soft tissue is well developed. The venous outflow channels are more abundantly represented than the corresponding arterial structures. This concerns particularly the metaphysial regions in a growing bone which appear as a veritable sponge-work of canals mainly occupied by veins (MORGAN 1959). The intimate relation between the bone medullary vessels and the deep veins of the extremity has been commented on by many investigators.

B. MEASUREMENTS OF BLOOD FLOW AND HAEMODYNAMIC CHANGES IN BONE

The blood flow in bone belongs to those parts of the circulation physiology where many essential questions, in spite of intensive research, remain unanswered. The physical properties of skeletal tissue have here been the greatest obstacle. Another aggravating circumstance is the occurrence of multiple inflowing and outflowing vessels of which the veins are relatively much more abundant than the arteries and which, moreover, are largely of a very small calibre. Common methods for blood flow measurement could not therefore be applied. The methods used are the following.

1. Skeletal perfusion

One of the first attempts to register the blood flow in bone medulla was made by DRINKER & DRINKER (1916). The tibia from dog was perfused under constant pressure through the nutrient artery; the bone was otherwise completely isolated from the body. The velocity in the outflow from the bone *in toto* was measured by drop recorder. Under these experimental conditions the authors stated that observed changes in the outflow were to be ascribed to changing vasomotor activities in the bone vessels. A fundamentally similar method was applied in later investigations by DRINKER *et al.* (1922).

CUMMING (1960, 1962) and CUMMING & NUTT (1962) cannulated the nutrient vein of rabbit femur. They mentioned that the outflow here measured by drop recorder represents the flow through the femoral medulla.

The shortcomings of these methods of measurement have been commented on by SHAW (1964). Besides the main nutritional vessels no regard is paid to other inflow and outflow channels for the blood essential for the bone, i.e. epiphysial, metaphysial and periosteal vessels, nor to the relation between skeletal blood flow and blood flow in surrounding musculature.

2 Venous occlusion plethysmography

EDHOLM *et al* (1945) tried by this method to measure the blood flow in the humerus in *homo* A plethysmograph was put over the distal third of the humerus An arterial occlusion was applied between the plethysmograph and the proximal occlusive cuff on a level where the main nutrient arteries have an intra-osseous course whereby the occlusion would not affect the flow in these vessels The proximal occlusive cuff prevented outflow through the main nutrient veins and the blood that was collected in the soft parts underneath the plethysmograph was considered to represent the entire venous blood volume from the mentioned part of the bone

This method was later criticised Apart from the main nutrient arteries it pays no regard to the other abundant arterial inflow that occurs or to the possibility of a venous outflow via the medullary cavity above the occlusion level (BRAUNSTEINER & GRABNER 1958 MCPHERSON *et al* 1961 SHAW 1964)

3 Radio isotopes

TUCKER (1950) was among the first to attempt to estimate the blood flow in bone with the aid of isotopes He utilized *the bone seeking property in* P^{32} and carried out studies in rabbit and then in *homo* The isotope was injected intravenously and after about one hour measurements were made of the emitted beta radiation from samples of bone The demonstration of the isotope in the tissue was considered to indicate a functioning circulation and the method was used for determining the viability in the femoral head With the same object the method was later applied by ARDEN & VEALL (1953) and BOYD *et al* (1955) in animal experiments as well as in *homo* These investigators moreover used a counting probe that made it possible to measure the radiation *in situ*

A disadvantage of the method was that at least at investigations in *homo* only small tissue specimens could be obtained and these were probably not representative for the whole skeletal region (TUCKER 1950) BOYD *et al* (1955) for several reasons considered the concentration of P^{32} in bone is not strictly a measure of circulation

FREDERICKSON *et al* (1955) were the first to utilize *the initial short term clearance of a bone seeking isotope* (Ca) from blood as a measure of bone blood flow The same method was used at later blood flow investigations with the aid of different isotopes P^{32} (DE JONG *et al* reported in COPP 1957) Ca (WEINMAN *et al* 1963 1964) Sr (WEINMAN *et al* 1963 1964 SHIM 1966 SHIM *et al* 1966 SEMB 1966 c) F^{18} (VAN DYKE *et al* 1965) These investigations were carried out in various experimental animals

FREDRICKSON & co-workers presumed that all tracer atoms were removed

from the skeleton at one single circuit of the blood and that the clearance value was a measure of the effective blood flow in bone This has never been proved and has been the object of discussion VAN DYKE *et al* (1965) made their calculations on the same presumption but did not rule out the possibility that the results for this reason could none the less be misleading According to WEINMAN *et al* (1963) the calcium and strontium radio isotopes are only incompletely eliminated from the blood of the skeleton, they state that the blood flow values indicate minimum blood flow in bone and should be interpreted as an expression of capillary flow

Cr labelled erythrocytes Another method of utilizing radioactive isotopes for blood flow measurements was introduced by GRAY & STERLING (1950) and STERLING & GRAY (1950) who in *homo* calculated the circulating blood volume with the aid of Cr^{51} labelled erythrocytes injected into the circulation BRODIN (1955) measured the activity from such labelled cells in the tibiae in rabbit The activity was considered to give a measure of the amount of blood in the investigated region so that a possible difference in blood amount in the two bones could be registered

Quantitative measures of red cell volumes in various parts of femur and tibia in rat based upon the dilution of chrome labelled erythrocytes have been established by BROOKES (1965)

A more dynamic picture of the blood flow in the skeleton is obtained by registration of the increasing activity in a bone during the initial period after systemic administration of chrome labelled erythrocytes WHITE *et al* (1964) WHITE & STEIN (1965) and STEIN & WHITE (1966) studied rabbit tibia with this method but SEMB (1966 *c*) considers the results unreliable because the method involves measurements made during a period of post ischaemic hyperaemia

A method based on a similar principle was devised by SAPIRSTEIN (1958) It is valid for many tissues that their content of intravenously administered *radioactive potassium isotope* or *rubidium isotope* during the first minutes after the injection is proportionate to the blood flow through the tissue TROTMAN & KELLY (1963) used Rb in this way for semi quantitative determination of skeletal blood flow in dog

Radio isotope depot clearance technique This method was described in 1949 by KETY for the determination of the regional circulation in individual organs If no significant loss of the depot material occurs via the lymphatic system the method is believed to give a measure of the effective capillary circulation The method was later applied for measuring skeletal blood flow with the J isotope PETRAKIS *et al* (1953) applied the technique on human sternal medulla The tibial and femoral medulla in rabbit (BRODIN 1955 BROWN GRANT & CUMMING 1962) as well as the tibial medulla in dog (LOWENSTEIN *et al* 1958) was investigated in a similar way

A survey of the literature shows that Larsen (1938) was the first to try to relate the intra-osseous pressure to the blood flow in bone. He was followed by many investigators who also used the intra-osseous pressure as indicator of the dynamics in the bone marrow circulation (Bloomenthal *et al.* 1952, Petrakis 1954, Susse 1956, Stein *et al.* 1957, 1958, 1959, Herzig & Root 1959, Weiss & Root 1959, Dickerson & Duthie 1963, Shaw 1963, 1964, 1965, Azuma 1964, Cuthbertson *et al.* 1964 a, 1964 b, Trueta 1964, Keck & Kelly 1965, Valderrama & Trueta 1965, Arnoldi & Linderholm 1966). The measuring method is relatively simple, it could be used clinically too. The intra-osseous pressure conditions have been studied under varying circumstances in *homo*, dog, cat and rabbit. It could throughout be established that the normal intra-osseous pressure is greater than the venous pressure. The average value of the pressure amounts to between one third and one fourth of the systemic blood pressure (Larsen 1938, Shaw 1963, Dickerson & Duthie 1963) but extreme individual variations have been observed (Herzig & Root 1959, Azuma 1964, Cuthbertson *et al.* 1964 a). At measurements in dog (212 bones) Cuthbertson *et al.* (1964 a) could demonstrate moreover considerable spontaneous pressure fluctuations in one and the same location.

Petrakis (1954) as well as Arnoldi & Linderholm (1966) considers the intra-osseous pressure to follow passively the pressure variations in the draining veins of the bone, whereas Susse (1956) is of the opinion that it reflects the pressure in the venous sinusoids. Other investigators point out that the measurement results are obtained from an artificial blood pool and therefore rather correspond to a pressure situated somewhat between the arterial and the venous (Bloomenthal *et al.* 1952, Herzig & Root 1959, Azuma 1964).

Uncertainty prevails concerning the extent that the measurement results reflect the intra-osseous blood flow. Azuma (1964) in support of his perfusion studies in dog reports that a close relation exists between the velocity of the medullary blood flow and the intra-osseous pressure. Valderrama & Trueta (1965) consider the intra-osseous pressure to give some idea of the outflow of blood from the bone. Braunsteiner & Grabner (1958) and McPherson *et al.* (1961) at blood flow measurements with thermo-electric method could observe obvious changes in bone blood flow without any appreciable simultaneous change in the intra-osseous pressure; therefore no consistent correlation between them seems to occur according to these authors. Most investigators establish merely that the measured pressure depends on arterial inflow and venous drainage.

3 Thermic methods

Attempts have been made to demonstrate changes in the local skeletal blood flow by registering *the intramedullary temperature* (JANES & MUSGROVE 1950 BRODIN 1955) Measured changes are difficult to interpret because not only blood flow changes but also changes in the local metabolism can be thought to lie behind them (JANES & MUSGROVE 1950) Considerable variations in temperature could also be registered from several points in one and the same medullary cavity (BRODIN 1955)

Another thermic principle introduced as early as 1902 by SHAKESPEARE is based on the fact that heat is transported away from a body warmer than its surroundings It is considered that the heat transport in a tissue can be influenced by changes in its blood flow (SUZUKI & TUKAHARA 1963) However no regard is paid here to tissue temperature variations, which can simulate a changed heat transport This has been shown in experiments by *inter al* JANSCO *et al* (1965)

The method was further developed in *the heated thermocouple principle* by GIBBS (1933) and later modified by GRAYSON (1952) and HENSEL & RUEF (1954) It consists of one junction of a thermocouple being heated above the tissue temperature while the reference junction is placed at an appropriate interjacent distance to prevent it being co heated Changes in surrounding tissue temperature do not influence the measure results because both junctions of the thermocouple are influenced to the same extent Changes in the blood flow through the tissue however are revealed as change of the heat clearance from the heated junction of the thermocouple that is to say as an apparent change in thermal conductivity of surrounding tissue A survey of the numerous investigations where this method is employed is given by GOLENHOFEN *et al* (1963)

With the object of increasing the sensitivity in the measuring probe some investigators have replaced the thermo element with thermistors coupled in opposition in a Wheatstone bridge (FELIX & GROLL 1953 SHAW 1963 LAWN *et al* 1964 *inter al*)

The above described temperature compensated flow velocity probe has been used extensively at blood flow investigations in different tissues Some investigations involve skeletal blood flow Among these can be mentioned measurements from human sternal medulla (GRAF & STEIN 1957 BRAUNSTEINER & GRABNER 1957 1958) and from femoral medulla in cat (McPHERSON *et al* 1961 SHAW 1963 1964 1965)

There has been animated discussion as to what extent the measured heat clearance depends upon the flow velocity Various reports contain contradictory information GRAYSON (1952) thus found a linear relation between heat clearance and flow at perfusion experiments in rabbit and sheep kid

ney and sheep spleen An approximative proportionality was observed by GRAF & ROSSEL (1958) at measurements of skeletal musculature (comparison with simultaneous drop recording) BETZ & HENSEL (1962) at perfusion of brain BETZ *et al* (1964) at experiments with kidney (comparison with volume determination of venous outflow and with inulin and PAH clearance) However, other investigators have only at low flow velocities found heat clearance proportionate to the flow through artificially perfused organs (LINZELL 1953 HENSEL & RUEF 1954 GRAF *et al* 1957) BILL (1962) established also that this linear relation at low flow velocities is found only if the measuring probe is influenced by the flow in vessels that are both small in calibre (as upper limit 180 μ is given for arteries and 450 μ for veins) and many in number The importance of the calibre of the vessels here has also been pointed out by BETZ *et al* (1966)

The measuring method must be regarded as purely qualitative (BILL 1962) but by suitable calibration with the measuring probe *in situ* it can be converted to a semi quantitative method (GOLENHOFEN *et al* 1963) or purely quantitative (BETZ *et al* 1966)

6 Vital microscopy

BRÅNEMARK (1959) studied the dynamics of skeletal blood flow by intra vital microscopy of bone medulla in rabbit fibula He could measure corpuscular flow velocity in the different vessel sections of the bone marrow as well as in capillaries in adjacent parts of diaphysial bone This method is the only one that permits the determination of flow direction in the circulation in bone

7 Non radioactive blood borne substances

ZINN & GRIFFITH (1941) injected *carbon particles* into the blood stream of rat They thought there was some relation between the blood flow and the distribution of the particles in different tissues Thus they investigated tibiae histologically after unilateral sympathectomy and observed signs of qualitative difference in the blood flow of the two bones

LAMAS *et al* (1946) estimated the circulation in bone medulla in relation to other tissues by injecting *indigo carmine* into the external iliac artery in dog They calculated the time required for the dye to become visible in skin in a superficial wound on the paw and in the bone medulla

Fluorescent substance The concentration in bone tissue of a fluorescent substance administered intravenously is measured with this method In order for the method to reflect to some extent the blood flow the measurement must be made before the tissue involved has had time to become

turated with the fluorochrome (BRODIN 1955).

Radiopaque material. The fact that fluid injected into bone marrow leaves it very rapidly and appears in extra-osseous vein trunks has been utilized in various ways. Infusions of different fluids have been given in this manner because intravenous injection has for technical reasons been difficult or impossible to carry out. Intra-osseous injection of radiopaque material, specially for venography, is used fairly extensively. (For survey, see HULTH 1956.) It has also been possible with this investigatory method to establish a varying drainage velocity of the contrast material from the *medullary cavity in different diseases.* JERGESEN (1956) and DICKERSON & DUTHIE (1963) determined the clearance velocity of intra-osseously deposited contrast material that would give a quantitative measure of the velocity of the venous outflow from the bone.

C. CONCEPT OF BONE CIRCULATION ACCORDING TO SKELETAL BLOOD FLOW MEASUREMENTS

Many measuring methods are, as can be seen from the above survey, purely qualitative, whereas others, with some reservations, give quantitative information.

High flow velocities could be established in bone tissues. FREDERICKSON *et al.* (1955) found them to be of similar size irrespective of the age of the animals (Ca clearance in rat) but WEINMAN *et al.* (1963) observed a more rapid flow in young animals compared with adult (Ca and Sr clearance in dog).

The velocity of the skeletal blood flow in dog is given by WEINMAN *et al.* (1963) as 5.6 ml/min/100 g tissue (adult animals), by SHIM (1966) as 10.2 ml, in both instances calculated on skeletal clearance of isotopes (Ca, Sr). Corresponding value for rabbit is 16 ml according to WHITE *et al.* (1964) (initial concentration of chrome labelled erythrocytes), 9.6 ml according to SHIM (1966), but CUMMING (1962) reports the considerably higher value of 51 ml/min/100 g tissue according to results at venous effluent collection. FREDERICKSON *et al.* (1955) report a flow velocity of 10—30 ml/min/100 g tissue for rat (bone clearance of Ca). As comparison it can be mentioned that the velocity of the blood flow in resting skeletal musculature is given as 3.5 ml/min/100 g tissue for *homo* (BARCROFT *et al.* 1952), as 3.4 ml/min/100 g tissue for dog (JONES & BERNE 1964).

The mentioned investigations concern whole skeletal parts. There is little information about the flow velocity in separate parts of a bone. According

to BRÅNEMARK (1959) (vital microscopy) the blood flows in the diaphyseal cortex at a higher velocity than in adjacent medullary parts Investigations with the aid of chrome labelled erythrocytes indicate that the arterial inflow is distributed in agreement with the degree of activity in different parts of the bone In growing rat this distribution between a metaphysis and a diaphyseal cortex is thus as 3 1 (BROOKES 1965) The blood flow to the ends of the bone seems to be significantly larger than to the shaft (bone clearance of Sr SHIM 1966) SEMB (1966 c) notes a high velocity (25—30 ml/min/100 g tissue) in the distal radial metaphysis of dog (plasma clearance of Sr by bone), which according to the author can to some extent be explained by the extensive vascularization in this region It is moreover well known that the venous outflow passages are specially abundantly represented in the ends of a bone and the high clearance velocity of intraosseously deposited radiopaque substance observed here indicates the rich flow in these channels (JERGESEN 1956 STEINBACK *et al* 1957 *inter al*)

At measurements of skeletal blood flow it has throughout been possible to observe a reduction of the flow when the arterial inflow through occlusion of the main artery of the extremity or of the nutritional arteries of the bone is reduced Various results however have been observed when the venous outflow from the bone was obstructed by occlusion of analogous venous structures A decrease of the skeletal blood flow has been registered in some cases (PETRAKIS 1954 SUSSE 1956 CUTHBERTSON *et al* 1964 a TRUETA 1964, VALDERRAMA & TRUETA 1965—intra-osseous pressure measurement WHITE & STEIN 1965—chrome labelled erythrocytes), at other investigations increased blood flow has been observed as a consequence of the mentioned procedure (MCPHERSON *et al* 1961 SHAW 1963 1964—intra-osseous pressure measurements thermo-electric methods)

DRINKER & DRINKER (1916) in their studies of skeletal blood flow reported a vasomotor activity in the intra-osseous vessels A stimulation of the nerves involved as well as administration of sympathicommetics resulted in a reduced bone blood flow Other investigators have in a similar way interpreted observed changes in intra-osseous pressure after sympathetic stimulation as a constriction of medullary arterioles resulting in reduced flow (HERZIG & ROOT 1959 WEISS & ROOT 1959 AZUMA 1964) After sympathectomy signs of increased skeletal blood flow have also been found by HERZIG & ROOT (1959) by means of intra osseous pressure measurement LOWENSTEIN *et al* (1958) and TROTMAN & KELLY (1963) made the same observation using radio-isotope methods

On the other hand investigations exist where the effect on the skeletal blood flow has completely failed to appear both after sympathetic stimuli

hould—when necessary—be carried out in fully conscious animals thereby avoiding an unphysiological effect by anaesthesia At an examination of the available measuring methods it was found that only the thermo electric method met the mentioned requirements This method allows a permanent implantation of the measuring probe which was earlier done in experimental animals using various types of probes in heart muscle (BETZ & BENZING 1963) and in brain (BETZ & HENSEL 1962 BETZ *et al* 1966) However these types of measuring probes which consist of thermocouples are hardly suitable for implantation in bone tissue from the aspect of strength as well as of size The principle of thermo electric flow measurement can be found on page 76

1 The measuring probe

At all work with electric measuring apparatus, the occurrence of artifacts, caused by the electronic equipment that comes after the transducer is directly correlated to the size of the primary signal Thus it is of the utmost importance that the measuring probe has the greatest possible sensitivity Therefore the two junctions of the thermo element were exchanged for two thermistors

Thermistors (NTC-resistances) of type U23UD (Standard Telephones and Cables Ltd) were used for the purpose These are unmounted bead thermistors each formed between two platinum alloy wires (2—3 cm long) where the glazed bead is approximately 400 μ in diameter They therefore well fulfil the requirement of small dimension In order to avoid errors caused by currents leaking to surrounding tissue a low resistance value in the thermistor is to be preferred the thermistor used has a resistance of 2 kΩ at 20° C Its resistance temperature characteristics show a practically linear course (deviation about 2 % for each 10° C) The thermal time constant is equal to 0 8 seconds

The thermistor bead is extremely brittle its two platinum leads are even more so They cannot be implanted in a tissue without protective covering which is in any event necessary from an electrical insulation aspect This covering as well as the insulating coating on the wires to which the thermistor is soldered must be of a quality that combines indifference to the tissue with great strength The end of the probe where the thermistors are situated must be able to withstand the rather harsh treatment unavoidable at the application into the bone tissue and the wires leading away from it are subjected to considerable mechanical strain precisely where they issue from the bone and at the continued passage past joints Various types of wire were tested The one that best met the requirements was a

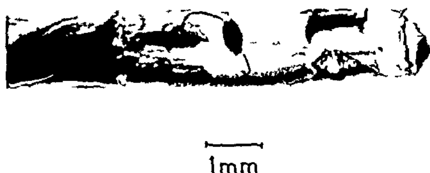


Fig 10 End of measuring probe with the two thermistors embedded in Araldite

teflon insulated 7 strand cable 0 5—0 6 mm in diameter Four of these were twisted firmly together and by simultaneous subjection to heat (approx +300° C) the teflon coverings were forced to deform in such a way that the total diameter of the cable amounted to about 1 mm At one end of the twisted cable the two thermistors were soldered 3—4 mm apart

The conventional manner of heating one thermistor is to utilize a separate heating coil Similar heating is achieved at the use of thermo-elements To restrict the dimension as far as possible a different principle was followed here (see below) This meant that further components were not needed in the probe

The terminal ends of the teflon insulated wires together with attached thermistors were bedded into ARALDITE D (CY 230) (Ciba) a casting resin of epoxy base which because of its indifference to tissue has gained wide spread use in medicine in connexion with chronic implantation Fig 10 shows the measuring end of a probe with one of the thermistors (the one that is later heated) superficially localized thereby establishing good contact with surrounding medium

ARALDITE D (CY 230) is a solvent free casting resin which after the addition of LANCAST A (100 40 parts by weight) hardens (+80° C 5—8 hours) to a product of good strength

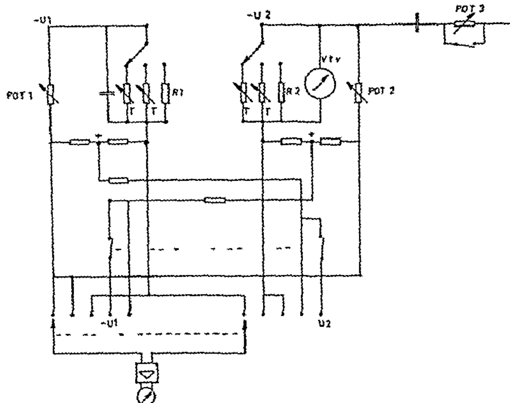


Fig 11 Measuring equipment *T* thermistors connectable in pairs which for the purpose of voltage calibration are exchangeable for the fixed resistances *R1 R2* *POT 1 2 3* variable resistances each composed of a 10 revolution potentiometer (200 Ω) and fixed resistances with known values connectable by steps *U1 U2* separate bridge voltages *VTV* vacuum tube voltmeter A recording unit can be connected parallel with the measuring instrument (shown at the bottom of the wiring diagram)

On the presumption that the two thermistors have identical temperature sensitivity they can be connected into the opposing arms of a *Wheatstone* bridge whereby changes in absolute temperatures do not upset the electric balance of the bridge because the result of these changes is that the resistances in both thermistors change in the same direction and to the same extent This presumes the use of matched pairs of thermistors which are obtainable but because a thermistor unit is easily damaged during mounting many of these pairs can be expected to be destroyed A more economic method of solving the problem is to use unmatched thermistors which in pairs are made equivalent from the standpoint of temperature sensitivity This can be effected by feeding them with currents of various size (see further the section headed *Equalization of temperature sensitivity*) This however requires also two separate bridges

2 Bridge construction (Fig 11)

The thermistors (*T*) are put on identical points of the two *Wheatstone* bridges With a double throw switch they can be replaced by another pair of thermistors or by fixed resistances (*R1* *R2*) The similarly polarized mid points of the two bridges can be connected across a measuring instrument the bridges can thus be balanced against each other Imbalances of the same size and in the same direction in the two bridges will therefore not affect the instrument

The applied bridge construction moreover allows the bridges to be connected separately with the measuring instrument which can also in other positions measure the separate voltages (*U1* *U2*) and these because of their polarity, can be balanced one against the other

Equalization of temperature sensitivity The voltage across a thermistor is according to Ohm s law equal to the current times the resistance In low voltage ranges the temperature sensitivity in the type of thermistor used is moreover a direct function of the applied voltage

Therefore by changing the mutual relation between the voltages of the two thermistors to a required degree the thermistors can be made to respond with equal resistance changes to a given temperature change i e to show the same temperature sensitivity This can be done in a practical way as follows

Under identical conditions (the bridge voltages *U1* and *U2* are balanced against each other) the two thermistor resistances (the thermistors put in a thermostat regulated water bath) are measured at two different temperatures (R_1 R and R_1^1 R^1 respectively) Information concerning the sought relation between the two voltages $\frac{U_1}{U}$ is then obtained from the equation

$$\frac{R_1 \times R_2^1}{R_1^1 \times R_2} = \frac{U_1}{U_2}$$

The relation is transferred to the voltage of the bridges as follows By means of the double throw switch the thermistors are cut out and replaced by the fixed resistances *R1* and *R2* (Fig 11) The potentiometers (Pot 1 Pot 2) in the other leg in each bridge are set so that their resistances are related to each other as *U* is to *U* according to the above formula Thereby in the bridges imbalances result that go in the same direction but are of different size whereby the sizes will relate to each other as *U* to *U* because they are functions of the resistances in the two potentiometers This is reflected as an imbalance between the bridges which can be read on the instrument The size of the imbalance in one bridge can now be changed by altering the applied bridge voltage (Here the sensitivity of the bridge for

the imbalance is changed.) The bridge voltage is adjusted until the fault signal assumes the same size as the fault signal in the other bridge, which is noted on the measuring instrument as a resultant balance between the two bridges. *The relation between the two voltages now established is* directly correlated to the relation between the resistances of the potentiometers, which in their turn represent the sought relation $\frac{U_1}{U_2}$. The voltages adjusted to the bridges are, in other words, adjusted in such a way as to eliminate differences in the temperature sensitivity of the two thermistors. *The relation between the voltages is easily read on the instrument by* balancing them against each other. An instrumental value of this nature is thus characteristic of each thermistor pair. After correction according to this value, each *thermistor pair was then tested in a thermostat regulated* water bath at two temperatures (+38° and +42° C) whereby it was established that the temperature sensitivity of the two thermistors was *equalized*.

As mentioned above, the linear relation between temperature sensitivity and applied voltage for the type of thermistor used prevails in the low voltage ranges (up to 0.5 volts). The author *has used as maximum* 0.25 volts D.C., i.e. this voltage was applied to the thermistor which primarily showed least temperature sensitivity. At these low voltages the thermistor *does not* "feel" the flow, a condition that has been controlled *in every* single case.

3 Heating device

To restrict the size of the measuring probe as far as possible, the author has avoided using the conventional heating coil around one of the thermistors. This is instead heated with low frequency A.C. (20 kHz). This has no effect on the direct current across the thermistor and thus not on its temperature sensitivity. An electronic filter prevented any effect on the other thermistor. The author has used in the thermistor an over temperature of 4° C in relation to the temperature of the surrounding medium. Because the ARALDITE *covering shows* a low coefficient of thermal conductivity (5.36 × 10 cal/cm sec °C) the surface temperature of the covering is considerably reduced. When measured, surface temperatures of about 2° C *higher than the temperature of surrounding medium were noted*. HENSEL & RUEF (1954) at measurements in muscle tissue found no signs of local vascular reaction at 3—4 degrees over temperature. BETZ & HENSEL (1962) recommended *the most suitable over temperature at measurements in* hypothalamus at 1—2 degrees. It must be added that these investigators used

measuring probes where the temperature fall to the surface is essentially less than occurs with the probes the author uses

After the A C supply had been switched on it took 3—4 minutes before stabilization of the temperature took place

The voltage across the heated thermistor was recorded with a vacuum tube voltmeter (Fig 11 V t v) So that changes in the thermistor resistance will be proportionate to changes in heat clearance it is necessary that the power developed in the thermistor be kept constant But this power depends on the thermistor resistance and to keep it constant frequent measurements are necessary of both voltage and amperage with adequate corrections of the latter However ROSENGREN (1961) has devised a method that eliminates these disadvantages The thermistor resistance is measured and the resistance in the heating circuit is equalized to it (In the author s apparatus this is done by a variable resistance [Fig 11 Pot 3] coupled in series with the A C source) This makes it possible to keep the potential fall across the thermistor constant A total deviation of the thermistor resistance of 4 % which is a high value at flow measurements in bone results in a maximum deviation in power of only 0 01 % according to ROSENGREN a deviation that lacks relevance here

4 Determination of heat clearance with the aid of thermistor probes

A body whose temperature is higher than that of the surrounding medium emits heat to it The heat transport is determined by the heat conductivity of the medium The heat conductivity displays an apparent increase if at the same time there occurs a convectional heat transport in the medium It is these apparent changes in the heat conductivity of a tissue conditioned by variations in the blood flow through the tissue that are registered with the heated thermistor The unheated thermistor merely eliminates the effect on the measuring unit by changes in the absolute temperature of the tissue

For the determination of the heat clearance (apparent heat conductivity) in terms of heat conductivity with thermistors the following applies

$$\lambda = \frac{K \; P}{\vartheta}$$

λ is the heat conductivity with the dimension cal/cm sec °C K is a constant conditioned by characteristics in the measuring probe P is the developed effect in the heated thermistor and ϑ is the temperature difference between the heated thermistor and the surrounding medium (the temperature in the unheated thermistor) This can also be expressed as follows

$$\lambda = \frac{k\ U^2\ k_t}{r\ \Delta R}$$

whereby U (read on the vacuum tube volt meter) indicates the voltage across *the heated thermistor* which *shows the resistance* r (obtained as potentiometer value) k_t is the temperature sensitivity factor (resistance change/°C) of the heated thermistor (determined by calibration at two temperatures) and ΔR indicates the resistance difference between the heated and the unheated thermistor (obtained as potentiometer values) $\frac{U^2}{r}$ can be regarded as constant (see the section headed *Heating device*)

This concerns also k ΔR is variable The size of k which is characteristic for each measuring unit is determined at stable temperature in a homogeneous medium with known thermal conductivity The author has used 30 % gelatine at +37° C ($\lambda = 11.0 \times 10^{-}$ cal/cm sec °C, GRAYSON 1952)

After various factors have been *determined in the indicated manner* the following is applicable to each individual measuring unit

$$\lambda = \frac{k_m}{\Delta R}$$

ΔR is thus inversely proportionate to heat conductivity its size can be determined with the aid of the measuring bridge potentiometer and variations in it can be continuously registered on a recorder

(Actually the expression should be written

$$\lambda = \frac{k_m}{\Delta R} - a$$

where a indicates a λ error conditioned by convectional heat transport via the wires of the measuring probe This factor however, is important only when the absolute value of heat conductivity is of interest but causes no error when estimating relative changes in heat conductivity)

Co-heating of the unheated thermistor can be a source of error With *the type of measuring probe used this was determined at about 2 % or less which can be considered of no practical importance* (cf GOLENHOFEN *et al* 1963)

5 Application of measuring probes in bone

As mentioned earlier the most reliable measuring results are obtained by this method from a tissue part with a large number of blood vessels of small and equal calibre The most suitable placing of the probe in a long bone—*in this case rabbit tibia*—would be in the metaphysis This however

is not practical for permanent implantation in a growing animal because the probe in that case would after some days be situated in the diaphyseal marrow cavity in contact with vessels of extremely varying calibre In order to get constant conditions the probe must be placed in an epiphysis in a growing animal For the present experiments the proximal tibial epiphysis was chosen in its more central parts the vessels are predominantly small in calibre

The measuring probes were applied as follows the animals were anaesthetized with Mebumal ether as earlier After the hind leg had been extended the skin was opened with a longitudinal incision (about 3 cm) over the thigh The proximal part of the tibia could be brought forward in the opening of the skin by flexion of hip and knee joints A thin guide wire was inserted from the lateral side by hand into the proximal tibial epiphysis straight through the layer of covering musculature The guide wire was of a flexibility that allowed no penetration of joint surfaces or terminal bone plate to occur An ordinary injection cannula having the same external diameter as the end of the measuring probe was passed over the protruding part of the guide wire with whose help it was inserted by hand into the epiphysis After the guide wire and the cannula had been removed the measuring part of the probe could be inserted under some resistance into this channel This gave it a stable position and no special fixation was necessary (Fig 12)



Fig 12 Thermistor probe *in situ* in proximal tibial epiphysis Magnification appr 5×

At the end of the experimental period the position of the probes in the epiphyses was checked by removing with a dental saw sufficient bone tissue to expose the intra osseous parts of the probes The restitution around the probes of the bone tissue that had been traumatized at the application was so pronounced that the probes, in most cases could not be removed without their being damaged therefore they could not be used in more than one experimental animal

A big problem was to prevent wear to the electric wires by the bony edge at the point where they issued from the epiphysis The wires were therefore drawn some distance through the covering musculature and brought out at the tibial tuberosity Here they were fixed by suture through the attachment of the patellar tendon so that pulling on them would not affect the intra osseous part of the probe

The wires were then drawn up under the skin to the middle of the back, where they were connected to a contact device (strip connector, 221—647, Amphenol Borg Electronics Corp) In order to fix this and also to protect it from mechanical damage it was mounted in a plexiglass holder (Fig 13) The base plate of this holder was attached under the skin by sutures in the back musculature The skin on the leg and on the back were then sutured

Every other day for one week the animals were postoperatively given penicillin (Penicillin procain Novo vet) in a dose of 100 000 I U /kg body weight

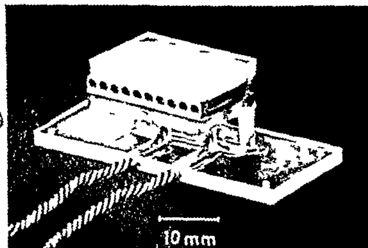


Fig 13 Connecting device The base plate is fastened subcutaneously to the back of the animal

C EXPERIMENTS

1 Preparatory measurements

At the experiments the same breed of white rabbits were u ed t earlier experiments As described the thermistor probes were applied two proximal tibial epiphyses

During the first post-operative days heat clearance showed very variations Thereafter these were reduced and in the measurin from each bone a tendency to fluctuate around a level appear d from day to day as well as during one and the same day could Heat clearances from the two bones agreed more rarely theref showed a parallel displacement At the same time as a st achieved which required 5—9 days the tendency of the measu be influenced by blood flow changes increased too Thi co with the aid of digital compression of the femoral vessels Th development was interpreted as the result of beginning heal the first time the heat clearance could be thought to re events in the epiphysis Before further experimental procedure taken the parallelity between the heat clearance values fro was checked for at least three days but usually longer Be desirable for the sake of comparison that the planned performed on animals of the same age as those used at th th stimulation experiments the probes must therefore be the animals as early as four weeks of age

It was also controlled by digitally pulling the cables w ued from the epiphyses that the ends of the probes were secur no change of heat clearance ensued

2 Suppressed blood flow, muscular activity

Various opinions have been expressed about what changes occur in the intra-osseous blood flow at changed outflow conditions in surrounding soft tissue Associated with this are also the diverging idea about the relation between skeletal flow and muscle activity

Five animals about six weeks old were included in this experiment l series Thermistor probes had been implanted 10—14 days earlier Stabl conditions from the standpoint of measuring values therefore prevailed the occasion of the investigation

The usual Mebumal-ether anaesthesia was given The femoral nerve the femoral vessels on one side were exposed at the inguinal ligament was divided in order to have access to the vessels proximal to where deep branches run off Loose ligatures were laid here around the femo

Under normal Mebumal anaesthesia left sided lumbosacral ganglionectomy according to the method described on p 58 was performed. Heat clearance and intraosseous temperature on both sides were registered post operatively for eighteen days. Several previous investigations of the circulatory changes after sympathectomy indicate that these occur during a rather limited early post operative period therefore clearance and temperature conditions were also studied during the hours immediately after the operation ½ 1 3 and 6 hours post operatively

In the same way as in the immediately preceding animal group, the position of the probes in the epiphyses was checked at the end of the experimental period. Those animals that showed infectious changes in the epiphyses were excluded here from the experimental series, too

After the end of the experimental period the noradrenalin content in the autonomous groundplexus of the tibial intramedullary arteries was also checked in all animals with the aid of the fluorescence method described on p 39

Useful data were obtained from 10 animals

Results — The difference between observed and predicted clearance value in the proximal tibial epiphysis on operated sides represents as in previous experiments the effect of the experimental operation on heat clearance. The measurement values from the pre operative period were treated in the same way as described above. The results are shown graphically in Fig 16. Pre operative observations are indicated by minus signs in front of the time figures, day zero is the operation day but the observation is pre operative

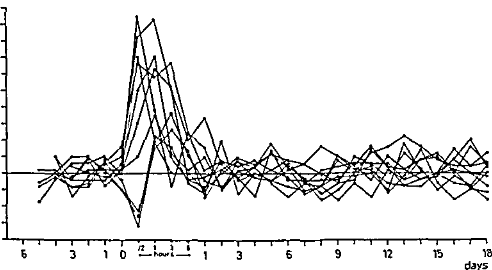


Fig 16

Heat clearance on the operated sides has a tendency to increase during the hours immediately after the ganglionectomy The increase is shortlived and the return to the original level usually occurs after six hours During the following post-operative period (a total of 18 days) the clearance values are distributed round the same level as pre operatively

At the statistical analysis of the obtained clearance values the hypothesis $a_1 = a = \quad = a$ was tested with the aid of variance analysis

	Square sum	Degrees of freedom	F
Time point	7565 53	21	6 76
Animal	1340 66	9	
Error	10067 24	189	
Total	18973 43	219	

The hypothesis is rejected with $P < 0\ 1\ \%$ (*** significance) However the hypothesis $a = a = \quad = a$ cannot be rejected The hypothesis $a = a$ is rejected with $P < 1\ \%$ (** significance) by 2 sided t test (The observation a was regarded as unreliable because the animals at this time were usually still unconscious as a result of the anaesthesia)

The analysis indicates that lumbosacral ganglionectomy has a significant effect on heat clearance on the operated side The effect is maximum 1 hour post-operatively and thereafter abates From and including the first post-operative day no effect can be observed from the experimental operation

As in the previous experimental series a comparison was made here between control sides and operated sides regarding the intra-osseous temperature during the experimental period Models and methods were used *analogous with those for corresponding calculations at peripheral nerve* sectioning With the aid of variance analysis the hypothesis that on average during the observation period no difference exists between control sides and operated sides was thus tested The following results were obtained

	Square sum	Degrees of freedom	F
Control-op	46 391	1	5 71
Animal	1186 891	9	
Error	73 097	9	
Total	1306 379	19	

The analysis shows that $1\% < P < 5\%$ i e there exists during the period on average a significant difference between control sides and operated sides *in the available material* An individual study of the observations 1 hour post-operatively (2 sided t test) shows that the difference at this point is not significant Only when the entire series is examined can it be established that a higher temperature exists on the operated sides

The investigation of the tibial intramedullary arteries shows that there is a complete absence of fluorescence *in the autonomous groundplexus of* the arteries on the operated side whereas corresponding vessels on the control side present a completely normal picture This concerns all ten animals

Data from the last two experimental series were also used for calculation of the mean values for heat clearance and intra-osseous temperature The observations from the control sides on the eighteenth post-operative day were used here (20 animals) Heat clearance $12\ 45 \pm 0\ 37 \times 10^{-}$ cal/cm sec °C intra-osseous temperature $39\ 61 \pm 0\ 23$°C In both instances 95 % confidence interval

D SUMMARY

The thermo-electric method for estimating blood flow with temperature compensated flow velocity probe was further developed for continuous registration of intra-osseous blood flow with permanently applied probes.

Intra-osseous heat clearance shows an unmistakable lowering at *arterial* as well as at *venous occlusion*.

Heat clearance is hardly affected by *isotonic muscle contraction* but shows an obvious lowering at *isometric contraction* under otherwise similar experimental conditions.

Tetanic stimulation of surrounding musculature after an initial brief increase produces a marked lowering of heat clearance as long as the stimulation lasts. It thereafter quickly returns to its original level. A further lowering occurs after the stimulation has ceased, when the neuro muscular system has previously been influenced by repeated brief tetanic stimulations.

The results referred to are not affected by previous sympathetic blockade with bretylium.

Peripheral nerve sectioning exerts a highly significant effect on heat clearance in the proximal tibial epiphysis. Maximum effect is obtained during the sixth post-operative day, whereafter it again decreases. The results indicate that after 9—13 post operative days it is lower on the operated side than on the control side. This tendency continues up to the end of the observation period, 18 days after the denervation.

The nerve division seems to have no effect upon the intra osseous temperature compared with the control side.

Lumbosacral ganglionectomy significantly influences heat clearance during the immediate post-operative hours. Maximum effect occurs 1 hour after the sympathectomy. Thereafter, there are no signs of effect from the experimental operation during the observation period involved (18 days).

After lumbosacral sympathectomy, the intra-osseous temperature is significantly higher on the operated side than on the control side.

Heat clearance in the proximal tibial epiphysis was $12.45 \pm 0.37 \times 10^{-}$ cal/cm sec °C, the *intra osseous temperature* registered in the same place was +39.61° C ± 0.23.

Summary and discussion

A survey of the literature that discusses various attempts to *stimulate* the skeletal longitudinal growth reveals a conspicuous divergence concerning the obtained results. Methodological errors are naturally of essential importance, and here an inadequacy in the recording of the *changed growth rate*, i.e. in the measuring methods, must be considered one of the most important factors.

Labelling with *tetracycline* in the skeleton—*the method the author uses*—provides excellent information about *inter alia* the endochondral growth from the growth plates (HULTH & OLERUD 1962, HANSSON 1964, 1967).

In the *present investigation*, the *endochondral growth* from the proximal growth plate of the diaphysis to the metaphysis in the growing rabbit tibia is taken as an indicator of the growth in skeletal length of this bone. No *estimate* of the *contribution* to the length of *the bone from the distal* growth plates or from the epiphyses in both ends of the bone has thus been made, nor have possible variations in the height of the growth plates been *observed*, *which could also affect the total bone length*. This *would not* necessarily be changed by accelerated growth in length in one section, the growth rate in other parts could at the same time be less than normal.

In view of the findings of other investigators, no regard was paid here to physiological anisomelia. According to GOFF (1960) and GULDHAMMER (1963) this in *homo* is insignificant. ARMSTRONG (1946) showed that the difference in weight of rat bone ash (front leg) is not significant, the radiocalcium uptake in right and left femurs of rabbit is equal (BOHR & SØRENSEN 1950). Growth studies covering short periods with tetracycline labelling revealed insignificant side differences that arose solely from the measuring method (HANSSON 1967).

The investigations were carried out on 6 week old rabbits. At this age more than [illegible]0 % of the growth potential remains in the tibia (HEIKEL 1960).

The absolute values of the growth in length of the proximal tibial metaphysis, tabulated for each experimental series, show great spreading also on the control sides. This was interpreted as an expression for a general effect—varying in degree—on the animals by the various operative interventions. Transperitoneally performed lumbosacral ganglionectomy, as well as open

ing the vertebral canal and dividing spinal nerve roots is naturally a major operation for a 6-week old rabbit. The absolute values on the control sides thus do not represent normal growth conditions, and all calculations of the effect of the various measures on the growth must therefore be based upon relative conditions. The mentioned general effect on the animals is expressed in a marked retarded and irregular growth during the first post-operative days, which made reliable measurements from this period impossible. For this reason, the first observations were not made until the third day.

The growth stimulating effect of various methods was generally ascribed to a changed intra-osseous circulation. Such a change has been attempted by *inter alia* direct traumatization of the investigated bone (trauma to the medullary cavity—sometimes with the simultaneous application of material into it—and fracture). These conditions make it difficult to analyse to what extent the observed effect must be referred to abnormal intra-osseous flow conditions or to determine whether it is also conditioned by extra-osseous disturbances in the circulation. These can be supposed to appear secondarily to the disuse of the limb, which to varying extent results from the trauma. In these circumstances, the author chose peripheral nerve division as stimulating method, whereby the operative intervention leaves the bone completely intact.

The results indicate that *the peripheral nerve sectioning* causes a highly significant accelerated growth in length in the proximal tibial metaphysis. This is most pronounced during the sixth post-operative day. The findings agree with those of RING (1961) who, however, did not observe the diaphyseal length in rabbit tibia until after two weeks and thus obtained the net effect of the stimulation over that period.

There is also reason to compare the results with initial growth acceleration as observed in a paretic extremity in children with poliomyelitis (SEELIGMÜLLER 1879, GREEN & ANDERSON 1955, LEBIQUE 1956, RING & WARD 1958, RATLIFF 1959). This acceleration is restricted mainly to the first year after the onset of the condition. Considering that it can here involve a somewhat different mechanism, it can be added that a year for *homo*, concerning skeletal ageing, corresponds to about 9 days for rabbit (HEIKEL 1960). This indicates, with some reservations, time parallelity between the growth acceleration at poliomyelitis and the acceleration that the author observed in rabbit after peripheral nerve division.

The noted accelerated growth in length of the operated side exceeds the growth of the control side by fully 20 %. It gradually reduces, and during the eighteenth observation day is significantly retarded on the operated side. The inclination of the growth curve indicates that the retardation during the immediately following period will be further pronounced. It is reason

able to presume that the course of development is analogous with that of poliomyelitis concerning change in bone length, i e the initial growth acceleration gives way in a later phase to a marked and more prolonged growth retardation the net effect of a peripheral nerve injury being retarded growth This agrees completely with earlier observations (ALLISON & BROOKES 1921 ARMSTRONG 1946 GILLESPIE 1954, COMBES *et al* 1960 *inter al*) experimentally as well as clinically

A sectioning of the femoral and the sciatic nerves causes *inter alia* a postganglionic sympathetic injury whose extent as far as concerns rabbit tibia the author has estimated with the fluorescence method (see below) The results point to a total sympathectomy of intra osseous arteries and harmonize with the described distribution condition of sympathetic fibres to structures in the extremities (KRAMER & TODD 1914 WOOLARD 1926 WEISS & ROOT 1959 *inter al*)

A peripheral nerve contains several components To investigate which of these is of importance for the noted bone growth stimulation a selective injury was done to the motor the sensory and the sympathetic component These studies however have only included the period around the growth maximum because the effect of the individual component can most safely be observed during this period

Sectioning of the anterior roots belonging to the spinal nerves L_7 S S_1 on one side causes a pronounced paresis in the corresponding hind limb The denervation results in an accelerated growth in length of the proximal tibia on the same side (highly significant) which from the aspect of time agrees with the effect of peripheral nerve division No quantitative comparison between these two effects can be made because it can be presumed that the degree of motor denervation is not the same in the two experimental series Further there are other qualitative differences RING (1961) observed also an accelerated skeletal growth in the tibia after motor root injury in dog but could see no effect from the same intervention in cat A reason for this can be that the root division in the former instance included more lumbal and sacral nerves than in the latter instance

The accelerated growth reduces after maximum on the sixth day following the same pattern as at peripheral nerve sectioning

The investigation of tibial intramedullary arteries showed no differences concerning fluorescent noradrenalin product (see below) However sectioning of anterior roots causes an injury to preganglionic sympathetic fibres but this does not affect the content of noradrenalin of corresponding postganglionic structures and therefore not the degree of fluorescence (FALCK 1962) Characteristic of the preganglionic fibres is also their over

lapping pattern in the paravertebral trunks whereby preganglionic fibres from intact levels can provide a preganglionic supply to ganglion cells that have been robbed of their original preganglionic synapses. The division of a smaller number of anterior roots thus will hardly affect the function of corresponding postganglionic structures (cf. MONRO 1959). New investigations (DAHLSTRÖM & FUXE 1965) however point to the anterior root also containing postganglionic sympathetic fibres. The disappearance of these at the applied method of root division is not reflected in the fluorescence pattern of the investigated vessels probably for quantitative reasons.

Retarded skeletal growth has been noted after *sensory denervation*. This has been thought to be due to an increased traumatization through disappearance of normal protecting mechanisms (RING 1961, TROUPP 1961). The author did not find this effect after sectioning of three posterior nerve roots. The measurements of length after this intervention rather indicate a somewhat accelerated growth during the sixth post-operative day. No significant difference compared with sham-operated animal, however, is found. An explanation of the suggested effect could perhaps be sought in the operational procedure. The opening of the dura and the division of a number of posterior roots probably cause also some traumatization of corresponding anterior roots without this being seen at the post-operative appraisal of the motility. This non visible motor injury can be the cause of the slight growth stimulation. Possibly an increased traumatization through the sensory loss can also be a contributing factor.

An injury to sensory roots could be thought to influence the skeletal growth by way of changed activity of the vascular smooth muscles through the interruption that occurs to dorsal root vasodilator fibres and to their transmission of so-called antidromic vasodilator impulses. However, the results of an extensive research in this field summarized by UVNÄS (1961) point to these fibres probably being pain fibres completely lacking functional relations with vasodilator centres in the central nervous system and localized, as are other pain fibres in the extremities, mainly in the skin.

At fluorescence microscopy the picture of the autonomic innervation apparatus of the intra-osseous arteries on the operated side completely agreed, as expected, with the findings on the control side.

The next step in the separation of the possibly active components at the growth acceleration after peripheral nerve sectioning was a selective *sympathectomy*. Considerable disagreement prevails whether the sympathetic nervous system exerts any influence on normal skeletal growth, and most experimental as well as clinical investigations fail to verify that a sympathectomy stimulates growth. One reason for the diverging results at

earlier investigations has probably been the limited possibilities for post operative control of the extent of the sympathectomy Even an extensive resection of paravertebral ganglions can result in an incomplete sympathectomy because of the great variation both in number and in localization of intermediate sympathetic ganglions (WRETE 1941 MONRO 1959)

A method that in each individual instance permits a control of the extent of such an intervention as well as of the effect from other measures (peripheral nerve sectioning anterior root sectioning) implying an interference with sympathetic structures must therefore be considered of fundamental importance The author has carried out this control by studying the noradrenalin content in the autonomic ground plexus of the intramedullary blood vessels This was done with the well documented fluorescence method according to FALCK & HILLARP and based upon the disappearance of the noradrenalin after postganglionic denervation (EULER & PURKHOLD 1951) As mentioned above no preganglionic injury is reflected in the fluorescence

A mapping of the postganglionic outflow to the rabbit tibia indicates that the lowest outflow occurs from the S ganglion in the paravertebral trunk and that the ganglions between the L and S_x levels must be resected in order to obtain a complete interruption of the postganglionic connexions to the intramedullary arteries of the tibia These results do not agree with earlier ones obtained by GOETZ *et al* (1955) According to these authors a removal of the ganglions L—L is sufficient to perform sympathectomy on the hind limb of rabbit They recorded the effect of the intervention by noting differences in the rate of warming of the hind limbs after precooling An existing difference in this rate however need not mean a complete sympathectomy moreover it is not completely made clear to what extent thermal changes can directly affect the vessel musculature (HELLON 1963) Furthermore the mentioned authors provide no information about where on the extremity these measurements were carried out Seen against the background of the present author s finding it is hardly probable that the recordings were made from the more peripheral parts of the limb where at the same time an accelerated skeletal growth could be observed

Lumbosacral ganglionectomy followed by control that the tibia on the same side has been completely sympathectomized has no significant effect on the growth in length of this bone according to present investigations However it must be noted that the observations for reasons given above did not begin until the third post-operative day and thus do not reveal any possible effect during an earlier post operative period

Because there are investigations including circulatory changes after sympathectomy indicating that an effect of the intervention remains for a longer time (TROTMAN & KELLY 1963) sometimes for several weeks (LOWENSTEIN *et al* 1958) the observation period was extended to include

eighteen days. However, no effect whatsoever on the growth in length is noted during this period. The author's finding is thus comparable with that of most other investigators.

When the results of the experiments referred to are compiled, it seems to be the motor component that is the underlying cause of the observed growth stimulation in tibia. A destroyed motor function means a muscular function reduced in varying degrees, an immobilization, and possibly also a disturbance of a trophic influence on the skeletal tissues by way of somatic nerves.

The question of a possible trophic influence on the skeleton attracted interest primarily in the beginning of this century (see CASSIRER 1912), but has also later been the object of discussion (HURREL 1938, MILLER & KASAHARA 1963, HULTH & OLERUD 1965).

In order to be able to illustrate the problem involved, the present author partially immobilized a group of experimental animals with intact innervation and studied the longitudinal bone growth after this measure, which means *division and partial resection of the Achilles tendon*. The endochondral growth in the proximal tibial metaphysis occurs at a higher rate (highly significant) on operated side than on control side post-operatively. The accelerated growth is most pronounced during the sixth post-operative day, concerning time, thus agreeing with the growth stimulation after denervation. After this time point, the acceleration reduces considerably and the difference between the two sides is no longer significant during the eighteenth post-operative day. Contrary to the growth conditions after peripheral nerve sectioning, no growth retardation is ever developed here. This was interpreted as a result of the reducing immobilization that could be observed towards the end of the observation period, when the function in the calf musculature began to return.

In the literature, there is at present little evidence for the existence of trophic influence on bone growth from the nervous system. The present results show that such an influence at least plays no dominant role for the growth acceleration that follows on peripheral nerve sectioning or division of anterior nerve roots. The immobilization appears to have the incomparably greatest importance here. However, it seems as though only quantitative importance could be ascribed to the immobilization method. The present results agree with the growth acceleration at immobilization earlier observed by *inter al.* ARKIN & KATZ (1956), and RING (1961).

There is much argument that at immobilization of varying extent of an extremity, the static and dynamic conditions that normally prevail between the bones and the musculature is disturbed. Ever since HUETER-VOLKMANN (1862), many investigators have studied the effects on the growth in

skeletal length that a changed mechanical influence can exert by means of changed pressure and tension conditions at an inactivation of the musculature However no unanimity has been reached about this

A haemodynamic balance exists also between skeleton and musculature, which can be affected by immobilization Numerous morphological investigations have thus established the rich vascularization of the bone tissue The arterial supply to musculature and skeleton occurs from the same arterial main trunks and the functional relation between the two arterial areas is very well developed especially in the muscle insertions at the end of a long bone That too, concerns the venous outflow which through an even larger abundance of anastomizing channels is connected with surrounding intramuscular veins and with the deep vein trunks of the extremity Under these circumstances bone and cartilage with surrounding musculature are regarded as one functional unit (GEISER 1957 BROOKES 1958 TRUETA 1961, 1964 RING 1961) where the muscular activity is of decisive importance for the blood flow in the bone (BLAIR 1938 HEALD 1951, MORGAN 1959)

It must be noted that earlier investigators (MULLER 1924 1928 STINCHFIELD *et al* 1949 GELBKE 1951 ARKIN & KATZ 1956) have not always taken into consideration that these two factors—changed pressure and tension conditions and disturbed musculo skeletal circulation—at the same time occur at an immobilization and can be of importance for a changed skeletal growth

They have both been interpreted by the present author as probable causes of the growth acceleration that has been observed

It is in the nature of things that no parameter of the mechanical element can be found The author has instead tried to observe the circulatory events in the bone under varying experimental conditions

For the estimation of *the skeletal blood flow* it was desirable to find a method that allows repeated registrations from one and the same animal This has earlier only been done by using intra osseous pressure measurements (CUTHBERTSON *et al* 1964 b KECK & KELLY 1965) and by using radio isotope depot clearance technique (LOWENSTEIN *et al* 1958) Both methods mean a traumatization of the bone marrow tissue The measurements which thus hardly reflect physiological conditions, can for this reason only be made a few times and usually not in the same tissue section a matter that makes it impossible to standardize the measuring conditions The results of intra-osseous pressure measuring is further obtained from an artificial blood pool this creates great difficulties in interpretation Moreover the fact that the measurements must always be made on anaesthetized experimental animals further limits the number of registrations Thermo-

electric method could be applied in a similar manner but with the same reservations regarding its usefulness However this method has been used in other connexions for observations covering a long period by permanently implanting the measuring unit in tissues (BETZ & HENSEL 1962 BETZ & BENZING 1963, BETZ *et al* 1966) Here repeated measurements can be made on fully conscious animals and the measurement values are always obtained from the identical tissue area where after a sufficient healing period conditions prevail that to some extent reflect physiological one The author chose this method for registering skeletal blood flow The physical properties of the bone tissue however offer considerable difficulties concerning construction and qualities in the measuring probes and none of the types earlier used at permanent application could be employed here The probes must be characterized by indifference to tissue great strength high sensitivity, and small dimension These qualities are found in the type of measuring probes constructed for the purpose of and used in the present investigation

The measurement principle is based on changes in the heat clearance of a tissue (apparent thermal conductivity) conditioned by changes in the blood flow of the tissue Justified criticism (*inter al* BILL 1962) has been directed to reports (*inter al* GRAYSON 1952) that sought to assert that a linear relation prevails between heat clearance and blood flow That this is not the case has been clearly shown by several investigations (BILL 1962 GOLENHOFEN *et al* 1963, BETZ *et al* 1966) The method is in itself purely qualitative, but can by calibration with the probe *in situ* be made semi quantitative (GOLENHOFEN *et al* 1963) or even quantitative (BETZ *et al* 1966) In the present investigation it was used exclusively qualitatively

Shortcomings in the measurement method lie in the fact that the measuring probe is only affected by the heat transport in a small surrounding tissue area with a few mm radius (GRAYSON 1952 GOLENHOFEN *et al* 1963) The registrations therefore reflect highly local blood flow changes, which are probably not representative of the total blood flow through the tissue involved It is reasonable however to presume that qualitative changes here follow one another

An inhomogeneity in the local heat clearance can simulate a blood flow change (LINZELL 1953) This source of error has greatest importance at long term measurements If it exists at the registration of rapid courses, it manifests itself as a displacement of the base line which is usually easy to discover The fault moreover, shows itself as a temperature gradient in the unheated probe and can be altogether eliminated at individual registra

tions of heat clearance values by checking the temperature balance both before and after such registrations.

GRAYSON (1952) showed that a linear relation exists between the water content in a medium and its thermal conductivity. A change in the fluid content of a tissue can therefore considerably affect the results at measurements of heat clearance over long periods. The importance of this fact for the present long term measurements is further discussed below.

The present investigation proved that the heat clearance value, in terms of heat conductivity, practically never agrees in the two tibial epiphyses in one and the same animal (pre-operative values). The explanation lies largely in the fact that the registrations cannot be made from identical points. The proximity of the probes to blood vessels can vary as can also the calibre of these vessels, which must necessarily influence the thermal conductivity. After application of the measuring probes, scar tissue is formed around them. A difference in the size and structure of this on the two sides must also essentially contribute to the difference in conductivity. The same phenomenon was observed at measurements in other tissues (GRAF & ROSELL 1958, BETZ 1965). This fact results in percentage calculations of the clearance changes on the two sides not being comparable.

The mean value of heat clearance in the proximal tibial epiphysis in rabbit was calculated from the control sides in twenty animals. The measuring probes were at these registrations applied in the bone for about 4 weeks. The mean value was found to be $12.45 \pm 0.37 \times 10^{-}$ cal/cm sec °C. The obtained mean value is higher than that noted by GRAF & STEIN (1957) in the sternum of patients (11.4 ± 2.95). It is true that, owing to the earlier mentioned error caused by convectional heat transport via the conductors of the measuring probe, the present mean value is somewhat too high. However, GRAF & STEIN appear to have disregarded this error. Therefore a difference in the fat content of the bone marrow in growing rabbit and in *homo* (the authors do not state the age of these) is, besides a possible species heterogeneity, a probable cause of the difference in the two mean values. The marked difference in the spreading of the two mean values is most likely due to the entirely different measurement conditions. GRAF & STEIN have recorded from pools of blood with greater or lesser element of coagulation, the present author obtained the measurement values from intra-osseous tissue with stationary vascular conditions.

The mean value of the intra-osseous temperature, calculated at the same time and from the same material as the above heat clearance value, measured on the control sides, amounts to $+39.61 \pm 0.23$° C. The relatively large spreading is caused by the registrations probably not originating from

identical points The physiological temperature field of an extremity (BRUCK & HENSEL 1953), characterized by both an axial and a radial temperature fall is decisive here.

An occlusion of the femoral artery results as expected in a lowering of heat clearance indicating a reduced intra osseous blood flow. An unmistakable lowering is also obtained by partial blockade of the venous back flow in the extremity by the *occlusion of the femoral vein*. The latter observation agrees fully with the findings of most other investigators (*inter al* PETRAKIS 1954, TRUETA 1964, VALDERRAMA & TRUETA 1965 (intra osseous pressure measurements), WHITE & STEIN 1965 (chrome labelled erythrocytes)). However according to MCPHERSON *et al* (1961) and SHAW (1963, 1964) that procedure results in an increased skeletal blood flow. These investigators have used the same method as the present author but with the measuring probes only temporarily applied in the bones which can have had decisive importance for the observed changes. The increase in intra osseous pressure through the venous occlusion can under these experimental conditions cause displacements of the probes simulating an increased heat clearance, a source of error that some authors (MCPHERSON *et al*) themselves have pointed out.

Stimulation of the peripheral cut ends of *the femoral and the sciatic nerves* produces changes in heat clearance indicating qualitatively similar changes of the intra osseous blood flow. Repeated *isotonic* muscle *contractions* (1/sec) cause a scarcely detectable lowering of heat clearance whereas a clearly marked lowering is noticeable at similar *isometric contractions*. It is reasonable to presume that at both types of contractions an increased blood flow of comparable size through the musculature occurs, thus a different diversion of blood from bone based on vascular resistance differences in the musculature in the two cases can hardly be the cause of the observed change in heat clearance. At isometric contraction the mechanical influence on both periosteal vessels and on musculo-osseous vascular connexions is probably greater, therefore an interference most likely occurs here especially with the venous outflow from the bone. This interpretation agrees with what others have found at intra-osseous pressure measurement (TRUETA 1964, VALDERRAMA & TRUETA 1965).

A *tetanus* of the musculature lasting for a few seconds is, after an initial brief increase, followed by a marked lowering of intra-osseous heat clearance. This rapidly becomes normal after the stimulus has ceased. The suggested initial flow increase probably represents a venous backflow because the compressing strength of surrounding musculature primarily acts on the

venous extra-osseous vascular bed (cf VALDERRAMA & TRUETA 1965) The absence of valves in many outflow channels from bone is the morphological condition that renders possible such a backflow CUTHBERTSON *et al* (1965) have also demonstrated by means of rontgenographic and tracer technique in dog that the femoral medullary cavity can function as a collateral venous drainage channel

The reduction of the bone blood flow that then follows is presumably an expression of the increasing mechanical interference to which the extra osseous vessels are subjected The rapid return to the original level by the blood flow indicates that the large muscular flow that characterizes a post exercise hyperaemia does not seem to disturb the inflow to the bone

After 8—10 repetitive tetanic stimulations with about 5 second intervals, the flow pattern in the bone was slightly modified After the stimulation had ceased the bone blood flow in this case did not immediately return to the control level, but showed a further reduction for a few seconds It seems probable that skeletal muscle blood flow after such a period of heavy work is relatively more increased than in previous experiments In situa tions of this nature, a marked peak flow occurs for a few seconds imme diately after cessation of exercise the flow then falls rapidly to a fairly steady level This temporary over shoot of flow in skeletal muscle might very well lead to a transient redistribution of flow from bone to skeletal muscle and hence explain the above phenomenon

After a rest period of 15—20 minutes the effect of a renewed tetanic stimulation is again identical with that first mentioned

Results that are completely identical with those described are obtained at stimulation experiments after previous blockade of the adrenergic fibres with bretylium which indicates that the observed flow changes do not depend on the sympathetic system

Against the background of the results referred to the skeletal blood flow appears in more ways than one to be sensitive to influences from activity in surrounding musculature Purely mechanical interference with the extra osseous vascular bed seems to be important The possibility of changed distribution conditions of the blood concerning vascular beds in skeleton and in musculature must also be taken into account

The author has found an obvious increase of heat clearance on operated sides after *peripheral nerve sectioning* The statistical analysis shows that the change is mostly pronounced during the fifth and to a somewhat higher degree during the sixth post-operative day Thereafter heat clearance tends to fall and from the eighth to the thirteenth post-operative day the clear

ance values show an increasing tendency to become negative in relation to the control sides

The question of the extent that heat clearance in these experiments reflects circulatory courses in the bone is of greatest importance. Earlier investigations indicate that bone tissue at immobilization shows signs of hypervascularization in the form of dilated vessels (LANDOFF 1942, GEISER 1957, GEISER & TRUETA 1958, VALDERRAMA & LITTLE 1965, SEMB 1966 b) more in number than is normal (GEISER & TRUETA 1958). This must mean *inter alia* that the blood quantity at a given time is increased. The fluid content in a tissue is important for its thermal conductivity and it might be possible that the observed changes in heat clearance are due not so much to changes in the blood flow as to changes in the amount of blood. Against this hypothesis is set the following: the morphological changes mentioned above are first noted after one week, thereafter they develop gradually up to and including the fourth week of immobilization, thus following a course that in regard to time is completely unrelated to the development of heat clearance observed by the author.

Because of the ability of the sinusoidal system to change volume (BRANEMARK 1959) the intra-osseous blood volume can perhaps increase also when the venous outflow from the extremity is suddenly held back, as happens at occlusion of the femoral vein. However, the author observed an unmistakable lowering of heat clearance as a result of this measure.

A series of earlier investigations with the use of other methods has mentioned increased blood flow at immobilization in both the entire extremity (KEMP *et al* 1947, ISHIG *et al* 1953, HULTH & OLERUD 1960, SCHRODER & SEYFARTH 1960) and in individual skeletal parts (SEMB 1966 a, b, c, SHIM *et al* 1966). Against the background of these findings and the above discussion it must be considered most probable that observed changes in heat clearance represent qualitatively similar changes in the bone blood flow.

The investigation of medullary blood (rabbit) disclosed a significant increase of pH and oxygen saturation after 10 days of plaster immobilization (SEMB 1966 a, b) which was interpreted as signs of increased blood flow in bone. Plasma clearance of Sr by bone in dog suggested also increased intraosseous flow, but not until after two weeks of immobilization (SEMB 1966 c) carried out in the same manner. All observed changes thereafter remained for more than two weeks. With reference to flow increase, a probable explanation of the time differences that are found between these results and those of the author can lie in the altogether different immobilization methods. Peripheral nerve sectioning of the kind that the author uses should result in a considerably more extensive inactivation of the extremity and

moreover, a disappearance of tonus in the affected musculature, whose counterpart is not found at plaster immobilization The supposition is con firmed by the observations of other investigators Measurements of bone blood flow, based on the initial short term bone clearance of Sr^{85} (dog rabbit) reveal that plaster immobilization after some initial reduction, re sults in a relative increase of the blood flow in tibia and calcaneus after two weeks of immobilization (SHIM 1966) whereas a significant flow in crease can be observed as early as one week after division of the sciatic nerve (SHIM *et al* 1966)

At a comparison of the development of heat clearance with the course of the growth curve after peripheral nerve division (Fig 15 p 97 and Fig 4, p 48) a parallelity appears clearly with some time lag during the latter part of the observation period The biggest increases in heat clearance oc cur mainly at the same time as growth maximum whereas the clearance values from operated sides fall below those of the control sides 2—4 days before the time when the accelerated growth in length changes to a retarda tion It is conceivable that the immobilization causes metabolic processes in the bone tissue which induce an increased flow However, if it is presumed that changes in heat clearance qualitatively reflect changes in the intra osseous blood flow the obtained results thus point more to the fact that the increased blood flow is the primary and that this results in an increased longitudinal bone growth The observed delay in this can be thought to be due to the stimulatory effect on the proliferating parts and on the hyper trophic degenerative parts of the cartilaginous cell columns manifesting itself after periods of varying length The deviation in the growth curve at day 9 has possibly the same background (Fig 4 p 48)

Present investigations indicate moreover that changes in the haemody namic balance between skeleton and musculature can be underlying causes of the observed flow increase at immobilization by peripheral nerve sec tioning Muscular activity seems normally to lead to a decrease of intra osseous flow by mechanical interference with mainly the venous outflow from the bone This indicates that the bone in an immobilized extremity would get more blood than a corresponding freely mobile extremity expres sed in an increased flow rate

Studies of the blood flow in skeletal musculature in dog HUDLICKA *et al* 1959 BASS & HUDLICKA 1960 1964) indicate that the flow after peripheral nerve division is increased as early as after 3—4 days and thereafter in creases further in order 35 days after the denervation, to be about 50 % higher than the flow in normally innervated musculature This condition

can perhaps be thought to cause a re-distribution of blood in the extremit[y] to the disadvantage of the bone tissue whereby the above mentioned flow increase is counteracted and replaced by a subnormal intra-osseous flow. The size of the flow increase in the musculature however makes this hypothesis scarcely credible: the author could see no influence on the bone blood flow by a moderate postexercise hyperaemia where the muscle flow considerably exceeds the percentage figure mentioned above.

A more probable explanation of the successively decreasing flow noted during the latter part of the observation period is that the rapid onset of the muscle atrophy mechanically interferes primarily with the outflow from the bone thereby conditioning an intra-osseous stasis. The dilated vascular structures seen in bone tissue at immobilization (cf. GEISER 1957, GEISER & TRUETA 1958, SEMB 1966 b *inter al.*) can be an expression for such a stasis. The markedly increased intramedullary pressure that SHAW (1964) observed in tibia in children with poliomyelitic extremity shortening can also confirm this hypothesis.

The intra-osseous temperature seems to provide no information about the skeletal flow conditions.

Sympathetic lumbosacral ganglionectomy according to the present investigation is followed by an increase of bone blood flow indicated by a significant rise in heat clearance. The observed flow increase however is of very short lived nature and a return to normal begins as early as after one day. LOWENSTEIN *et al.* (1958) and TROTMAN & KELLY (1963) using the radio-isotope method have also observed increased intra-osseous flow after sympathectomy. The question of the duration of the flow increase after sympathectomy (also concerning soft parts) has been the object of very lively discussion without unanimity being reached. The author's result agrees with those of several other investigators (BARCROFT & SWAN 1953, LAMBERT 1957, 1960, SCHONBACH 1964). These have also noted an increase in the flow (the entire extremity) but with return to the original level after a few hours or days.

The flow increase can be explained by the sudden disappearance of tonus of the intra-osseous vessels at the ganglionectomy and a normalization of the flow probably indicates a return of vascular tonus presumably through a sensitizing of the vascular musculature for circulating noradrenalin (MACMILLAN *et al.* 1962). The basal vascular tonus, established by local mechanisms which characterizes most vascular circuits is perhaps of importance here too (FOLKOW 1964).

The results of the heat clearance measurements agree well also with the observed effect on the longitudinal skeletal growth. The effect of the brief

initial flow increase during the first day can be expected to be insufficient to be reflected in the first observations of the growth in length which do not occur until the third post-operative day After this there are no signs either of increased blood flow or of increased growth

The author could not find a satisfactory explanation for the noted higher intra-osseous temperature on sympathectomized sides

General summary

Earlier investigations on accelerated skeletal growth are surveyed

The longitudinal skeletal growth in rabbit tibia was studied with the aid of intravital labelling with oxytetracycline under varying experimental conditions, including interference with different nervous functions and partial immobilization by intact innervation

The distribution of postganglionic sympathetic fibres to tibia in rabbit was mapped

Earlier methods of measuring skeletal blood flow are discussed and a method for long term measurements of intra-osseous blood flow based on the heated thermo couple principle of Gibbs was developed

Qualitative blood flow measurements in the proximal tibial epiphysis were made Here was studied the relation between muscular activity and blood flow in the bone as well as the haemodynamic changes in skeletal tissue at simultaneous stimulation of bone growth and after sympathectomy

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Study on Arteriosclerotics Undergoing Amputations

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FROM THE CLINIC FOR ORTHOPAEDICS AND TRAUMATOLOGY, UNIVERSITY CENTRAL HOSPITAL, HELSINKI (HEAD: PROFESSOR K. E. KALLIO, M.D.)

STUDY ON ARTERIOSCLEROTICS UNDERGOING AMPUTATIONS

INCLUDING PRE- AND POSTOPERATIVE PERIODS

by
EERO VANKKA

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PREFACE

The subject of this study was suggested by my teacher and present principal Professor K E Kallio M D Head of the Clinic for Ortho paedics and Traumatology of the Central University Hospital Helsinki He has unsparingly given his advice and positive criticism at all stages of this work and I am very happy to have this opportunity to express my deep gratitude for his encouragement

My sincere thanks are also due to Associate Professor E V S Koskinen M D for much valuable advice and for the interest he has shown in my work

Furthermore I am indebted to Docents K Solonen M D and H Jul kunen M D who kindly gave me valuable advice

The mathematical treatment of the results and their graphical re presentation including part of the tabular arrangement is the work of Mr U Attila M Sc who also translated the manuscript into English Many thanks are due to him for this help as well as to Mr K Hart M A who revised the English manuscript

My thanks are also due to the Librarian of the Clinic for Orthopaedics and Traumatology Mr Y Sumes who aided me in finding relevant references

Helsinki 1957

E Vankka

CONTENTS

I INTRODUCTION

A General

Fairly little scientific attention was paid prior to the second world war to extremity amputees in Finland or in any of the Scandinavian countries for that matter (see Kallio 1943) As a result of the wars in which Finland was involved (1939—1940 and 1941—1944) our country acquired about 5000 new extremity amputees (Solonen 1965) and of them about 3800 were leg amputees (Bakalim 1966) Kallio (1943) has been a pioneer in their investigation in Finland, and a lively pursuit of this subject followed e g through the contributions of Hagelstam (1946) Langenskiold (1946) Kallio (1947 1948 1949a b c 1950 1951, 1959), Solonen (1956 1958a b c 1959 1961 1965) Bakalim (1964 1965) and Lindqvist (1966)

On the other hand those subjected to amputation on account of arteriosclerosis have not received as much attention Lindholm (1964a b) is the only one who has previously studied them in this country

In spite of the fact that amputation surgery is as old as surgery itself amputations undertaken on account of arteriosclerotic gangrene were anything but common a hundred years ago For instance, according to Buel (rev by Dale and Jacobs 1962) gangrene was not responsible for even one of the 91 amputations performed in the New York Hospital during the period 1839—1848

But with the increasing life span of the population gangrenes caused by arteriosclerosis have continuously increased in number This has been observed e g in Finland (Lindholm 1964b) and in Sweden (Hansson 1964) during the past 20—30 years and the same trend of development seems to persist For instance, with unchanged indications for amputation the annual number of amputations in the town of Malmo Sweden is expected to increase by 50 % from the 1955 figure by the year 1970, according to Alffram and Holmquist (1961) and in Gothenburg Sweden an increase by 75 % from 1962 to 1970 will occur according to Hansson (1964)

It would seem too that in Finland the number of persons subjected to amputation on account of arteriosclerotic gangrene is also continuously increasing. This suggests that it is most appropriate to study the problems encountered in patients suffering from gangrene.

It is thus to be understood that the fairly general occurrence of arteriosclerotic gangrene and of amputation necessitated by it is a rather recent phenomenon. Obviously, therefore, questions rating closer investigation are still to be found in this particular field. For instance, rather little attention has been paid in studies concerning amputees to the gradual development of the underlying chronic disease, arteriosclerosis, or to the extent it reaches at different phases in the history of the amputee — from the appearance of the first symptoms of occlusion to the fatal termination. Accordingly, this is one of the aspects for which elucidation is sought in the present work. At the same time it is desired to study the effect of sympathectomy as an expedient obviating amputation. Another object is to ascertain what results have been gained with amputation, bearing in mind that the patients concerned are suffering from arteriosclerosis and in whom gangrene, too, is only one of the manifestations of this disease.

B. Definition of arteriosclerosis, the classification of vascular diseases

Lobstein (1829, rev. by Pickering 1963) was the first to use the term "arteriosclerosis" to describe any cicatricial macroscopic hardening of the artery (sclerosis), its thickening and changes in its walls, independent of their aetiology. Even the diligent research of recent decades has not produced any aetiological definition of arteriosclerosis. There has consequently been no choice other than artificial classification and descriptive definitions.

Marchand (1904, rev. by Pickering 1963) first distinguished atherosclerosis from arteriosclerosis. The definition of atherosclerosis has caused dispute. The definition given in the Technical Report of the World Health Organisation (Ser. No. 143, 1958) is: "Atherosclerosis is a variable combination of changes of the intima of arteries (as distinguished from arterioles) consisting of the focal accumulation of lipids, complex carbohydrates, blood and blood products, fibrous tissue and calcium deposits and associated with medical changes." In the opinion of some authors

ties thrombotic changes are also associated with atherosclerosis For instance Allen et al (1962) propose the addition and often complicated by partial or complete thrombotic occlusion of the lumen

Schettler (1961) comes rather close to Lobstein s original conception in saying Fur uns ist die Arteriosklerose der Sammelbegriff chronischer arterieller Umbauvorgange die zu Verhartung Elastizitatsverlust und Lichtungseinengung der Arterien fuhren konnen und damit Funktions storungen der versorgten Organe bewirken (To us arteriosclerosis is the *collective notion of chronic arterial rebuilding processes* which may result in hardening loss of elasticity and reduced lumen of the arteries and thus cause functional derangement of the organs supplied)

Atherosclerotic changes in the late or complication stage of the abdominal aorta and of the medium large arteries of the extremities are referred to as arteriosclerosis obliterans According to Allen et al (1962) this is a diagnostic term having as synonyms atherosclerosis obliterans *occlusive peripheral arteriosclerosis* *arterielle Verschlusskrankheiten* (occlusive arterial diseases) and endarteritis obliterans

Several suggestions have been made for the classification of vascular diseases (Wright et al 1941 Ratschow 1959 Allen et al 1962 Pickering 1965 etc) However the pure forms stated in the classifications are rare Mostly various combinations of them are concerned (Linzbach 1958)

From the clinical point of view the height of occlusion is significant because the *localization of arterial lesions not only determines the symptoms* but is also of consequence as regards prognosis and therapy (Leriche 1955 Krautwald and Volpel 1959 Ratschow 1959 Allen et al 1962) A classification that has proved rather serviceable is the topographic division of chronic arterial occlusion diseases according to Ratschow on the strength of the localization of obstructions the peripheral lower leg pelvic and shoulder region and carotid types of occlusion In the lower extremities in particular however mixed types are often encountered when several occlusions occur at various heights (Heine et al 1965)

C Genesis of obliteration symptoms

Before arteriosclerosis becomes clinically manifest in the form of obliteration symptoms slowly increasing changes have been in progress in the intima often for as long as 20—30 years fatty streaks and fibrous plaques From the fifth decade onwards the effect of thrombosis begins

to produce symptoms of obliteration and ischaemic changes of the organ or tissue supplied by the affected artery leading to cardiac infarction apoplexy and/or the occurrence of gangrene in a lower extremity (Allen et al 1962 Sandler and Bourne 1963)

The disease may remain completely dormant even in the case of fairly severe arteriosclerotic patho anatomical changes unless it is accompanied by obliterative thrombosis (Scheidegger 1965) This is because more than 70 % of the lumen of the artery has to be occluded (Schoop 1964) even up to 90 % (Wylie and McGuinness 1953) or still more (Brice et al 1964), until the blood flow is reduced to such an extent that symptoms appear

The widespread nature of thrombosis is not always dependent on the severity of the atheroma formations (Schoop 1964) Its clinical significance arises from the fact that occlusion proceeds rapidly, frequently leading to complete occlusion and when vital organs (brain heart) are concerned to death (Mittelmeier 1959) Just as the commonest complication of atherosclerosis of the coronary arteries is thrombosis the commonest cause necessitating amputation of lower extremities in arteriosclerotic patients is likewise the occurrence of a thrombus (Edwards and McAdams 1953) For instance, Wessler and Schlesinger (1953) observed a fresh completely occluding thrombus in about 50 % of 66 patients subjected to amputation on account of arteriosclerosis in 25 % the thrombus was multiple

Factors other than the degree of obliteration influencing the clinical picture are the extent number and rate of development of obliterations, the distance of the proximal limit from the aorta, the efficiency of collateral circulation and general circulatory conditions (Munk 1959 Mittelmeier 1959 Ratschow 1959 Allen et al 1962) Munk (1959) said very pertinently that the development of arteriosclerosis into a manifest disease depends on how where and when it occurs

D Factors promoting development of arteriosclerosis

It has become increasingly general to accept a polyaetiology as an explanation of arteriosclerotic changes A number of causes have been observed which have been found to aggravate the arteriosclerotic changes

In the following the effect which some such predisposive factors such as age diabetes sex and blood pressure exert on the development of arteriosclerosis will be considered

Age

Age in itself cannot be considered a cause of arteriosclerosis but it is a time factor in accordance with which the number of arteriosclerotic patients the degree of severity of the disease and its fatal complications increase (Schinz and Reich 1955 Bredt 1961)

Roberts et al (1959) in an autopsy material of 500 patients observed an increase of arteriosclerotic lesions with age both as regards extent and degree of severity There were variations in these respects in different parts of the vascular system however In the lower part of the abdominal aorta changes were encountered in subjects of all ages Segmental occlusion of the aorta and of the iliac and femoral arteries was found to occur in the fifth or sixth decade in most instances The rate of sclerosis is slower in the intestinal region up to the age of 70 comparatively few changes occur in the splenic mesenteric coeliac and renal arteries

Arteriosclerotic obliterations causing lower extremity amputation are rare in persons younger than 50 years For instance in Hansson s (1964) series all but one of 236 patients subjected to amputation on account of arteriosclerosis were over 50 years and 59 % were older than 70 In the series of 284 amputations at the lower leg or thigh of Dale and Capps Jr (1959) those performed because of arteriosclerosis numbered 259 The age group above 50 and that above 70 years accounted for 92 % and 46 % of the series respectively

Diabetes

On the strength of autopsies and clinical studies the incidence of arteriosclerosis has been found to be distinctly higher in diabetics than in non diabetics (Dry and Hines 1941 Roberts et al 1959 Schettler 1961) The longer the diabetic affection the higher is the probability that arteriosclerotic circulatory disturbance ensues According to Scherf and Boyd (1955) 90 % of the diabetics whose disease has persisted for ten years display signs of arteriosclerosis

According to Lempke et al (1963) amputation ensues on an average three years earlier in arteriosclerotics with diabetes than in non diabetic ones and according to Schumacker (1951) even as much as seven years earlier Diabetes increases the amputation frequency (Bell 1950 Clhugus et al 1958 Lempke 1963) and diabetics undergo bilateral

amputation in a higher proportion than non diabetics (Joslin 1944, Silbert and Haimovici 1950) Sclerosis of the coronary and cerebral arteries is affected by diabetes too though not as strongly as that in the lower extremities (Clawson and Bell 1949, Roberts et al 1959)

Sex

Differences in the development of arteriosclerosis have been noted between the sexes In men arteriosclerosis begins to develop earlier and with greater intensity than in women the difference is most distinct in respect of the coronary arteries and those of the lower extremities (Barr et al 1955 Walker et al 1956 Lew 1957 Roberts et al 1959) Women are fairly free of arteriosclerosis up to their menopause whereupon after reduction of their oestrogen secretion the arteriosclerosis grows worse to such an extent that changes are encountered in equal degree in both sexes between the ages of 70—80 years (Barr et al 1955 Roberts et al 1959)

The occurrence of arteriosclerosis of the lower extremities in men and women in different age groups is illustrated by the following proportions for persons between 50 and 70 years, Hines and Barker (1940) found a men/women ratio of 6 1 and Ratschow (1959) 5 1 At ages below 60 years this ratio is 11 1 according to Hines and Barker The series assembled of persons amputated on account of arteriosclerosis show a predominance of males in agreement with the preceding For instance the series of McKenzie (1953) of amputees older than 65 years had a male component of 66 % In that of Dale and Jacobs (1962) the contribution of men was 65 % and in Lindholm s (1964b) series 59 %

This sex dependent difference becomes quite small with increasing age or is in fact inverted Series consisting mainly of geriatric patients have been reported to include men at 55 % (Alffram and Holmquist 1961) and at 40 % (Lindholm 1964a) Persons with coronary affection too show a distinct difference between the sexes For instance Oliver and Boyd (1954) found for the proportion of men and women in the age group of 50—59 years a ratio of 5 1 while in the group of 60—69 years the share of women had already increased so that the ratio was 2 1

Blood pressure

Numerous studies have demonstrated that chronic arterial hypertony promotes the development of arteriosclerosis (Nordman 1929 Kathke

1955 Konn 1956 Liebegott 1959 etc) Hypertonia is in fact in addition to diabetes the most significant disease contributing to arteriosclerosis Apart from its general effect increased arteriosclerosis of the coronary arteries is most notable among the changes observable in different organs (Baurle 1951 Spandling 1956 Roberts et al 1959 Schettler 1961 etc)

In the pulmonary circulation too hypertonia exerts an arteriosclerosis increasing effect on the pulmonary arteries (Merkel 1947 Konn 1956) Wilkins et al (1959) observed arteriosclerotic changes at autopsy in the cerebral and renal arteries in obese hypertonics in addition to the coronary arteries to a greater extent than in non hypertonics of the same age Chronic hypertonia has no distinct effect on obliterative peripheral arteriosclerosis of the lower extremities (Juergens et al 1960) nor is hypertonia present in any higher proportion of those subjected to amputation of lower extremities on account of arteriosclerosis than in non amputated persons of the same age (Spandling 1956 Juergens et al 1960)

II OBJECTS OF THE PRESENT STUDY

The principal purpose of this study was to follow in patients subjected to amputation on account of arteriosclerosis the gradual development of their fundamental disease from the first symptoms of obliteration through the sympathectomy and amputation stages up to death

Closely associated with this topic is the question of how such a least desirable measure as amputation might be avoided Sympathectomy is discussed as a prophylactic expedient

When, however amputation must be performed, it is important to know how it should be done in order that the best possible result can be achieved in the light of associated diseases operative mortality, technical success of the operation and rehabilitation Attention is also paid to these factors Attempts have been made to find answers to the following questions

(1) What was the kind of gradual development of arteriosclerosis revealed by the clinical symptoms of obliteration present prior to amputation?

(2) How extensive were the arteriosclerotic changes at the time of amputation?

(3) What was the extent of arteriosclerotic changes revealed by autopsies and death certificates?

(4) What was the contribution of sympathectomy as a therapy precluding amputation?

(5) What was the effect of the height of obliteration in the lower extremities and of other potential factors on the healing of the stump after amputation?

(6) What is the post amputation prognosis as regards the use of a prosthesis life expectancy and cause of death?

III MATERIAL AND METHODS

A Material

The clinical series involved in the present study consists of 184 lower extremity amputees who were subjected to amputation at the lower leg or at the thigh during the period 1950—1965

Amputation was performed on 97 patients between 1958 and 1965 in the Clinic for Orthopaedics and Traumatology Central University Hospital Helsinki and on 87 patients in the former Hospital of the Finnish Red Cross between 1950 and 1959

The series constitutes a selected material All told 296 amputations below or above the knee were carried out in the two hospitals in question during the above mentioned period Of them those 184 patients were included in the present series in whom the cause necessitating amputation was gangrene or a severe ischaemic condition due to arteriosclerosis The series from both hospitals have been combined and treated a one single series

Of the 184 patients 138 (75 %) were hospitalized other than for the purpose of amputation on account of either obliteration symptoms due to arteriosclerosis or diabetes Thanks to this when the results of examination at the time of amputation and data concerning sympathectomy operations were gathered information was available from 98 case reports from internal medicine hospitals and 72 from surgical hospitals in addition to 216 case reports covering amputations This amounts to a total of 386 case reports with associated laboratory and X ray examinations

For all 127 patients established as dead at the time of follow up study information concerning the causes of death entered in the death certificates has been obtained from the Central Office of Vital Statistics of Finland

Autopsies were performed on 32 patients Autopsy records concerning all these patients have been available

Of the 57 surviving patients, 38 (67 %) were subjected to follow up study The shortest and longest periods between amputation and follow up study were 13 months and nearly 14 years the average interval being four years Of the 38 patients, 30 presented themselves for follow up examination while the examination of the other eight was performed at the homes for old people or invalids where they were being cared for Nine of the 19 patients not included in the follow up study lived at a considerable distance Of the other ten whose homes were in the vicinity of Helsinki seven failed to present themselves for examination, while three could not be contacted

Distribution by age, sex and height of amputation

In the present report, the age at amputation is understood to be the patient's age at the time when the first or only amputation at a height above the ankle was performed Unless otherwise stated, reference to the patient's age in the following will mean his age at the time of amputation

With regard to the height of amputation distinction is made between amputations at the lower leg and those at the thigh No other kinds of amputation occur in the present series except for one exarticulation of the knee which has been placed with the lower leg amputations In that instance too, later reamputation at the thigh was performed

The primary amputation is understood to be the first amputation performed at a height above the ankle Any amputations performed after the primary amputation on the same extremity are referred to as reamputations

Fig 1 shows the distribution of the amputees by age and sex In addition, the figure indicates the contribution of diabetics to each ten year age group and their percentages of the entire male and female series The men number 111 (60 % of the entire series) and the women 73 (40 %) The older age groups contain a greater number of women than men while a predominance of men is noted in the younger groups The largest male age group is that between 60—70 years comprising 50 patients or nearly one half (45 %) of all the men The largest female ten year age group is that between 70—80 years, consisting of 33 patients or 45 % of all women

The mean age at amputation is found to be 66 2 years for the men and 72 4 years for the women The difference in age (6 2 years) is statistically

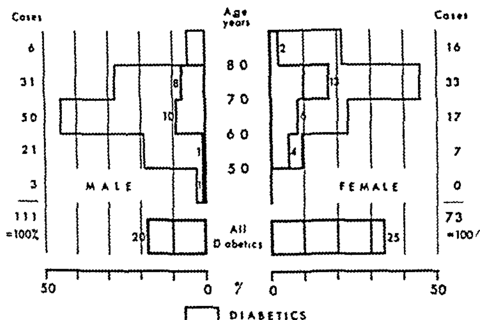


Fig 1 Age distribution of the male patients (111) and female patients (73) of the series for different ten year age groups in per cent The shaded portions indicate the contributions of diabetics and the separate shaded bars the percentages of diabetics in the male and female subseries regardless of age

highly significant ($P < 0.001$) according to Student's t test The mean age in the entire (male and female) series is 68 7 years Only three men were subjected to amputation at an age under 50 years Altogether 153 patients (83 %) were older than 60 and nearly one half of the patients in the series (47 %) were over 70 years at the time of amputation The oldest patient was 92 years old and the youngest 47 Both were male

The diabetics in the entire series number 45 (24 %) Of the women 25 (34 %) had diabetes and of the men 20 (18 %) the difference between these percentages is statistically almost significant ($P < 0.05$) according to the χ^2 test The mean ages of the diabetics and non diabetics were 68 2 and 68 8 years respectively The corresponding figures for the men alone are 66 9 and 66 2 years for the women 69 7 and 73 8 years No statistically significant differences were established between the diabetic and non diabetic groups in respect of age at amputation The average period of treatment for diabetes prior to amputation was 3 1 years, and the mean age at which diabetes was established was 62 2 years The treatment for diabetes consisted of insulin in 21 cases (47 %) which was used at 20—112 I U per day (average 56 I U per day) Ten

tients received peroral tablet treatment, and the other 14 managed by diet

From Fig 2 the numbers of final lower leg and upper leg stumps and their distribution by sex and age can be seen Moreover the diabetics' stumps have been indicated for all ages in aggregate

The 219 stumps itemized in Fig 2, which belonged to 184 patients came about as follows Primary lower leg amputation was performed on 24 extremities Nine of them (38 %) had to be re amputated later, in two instances at the lower leg and in seven at the thigh The end result was 17 lower leg stumps and seven upper leg stumps Correspondingly, primary amputation at the thigh was performed on 195 extremities of which nine (5 %) had to be subjected to later reamputation The total is thus 219 primary amputations and 18 reamputations (8 %)

The 219 final stumps comprise 17 lower leg stumps (8 %) and 202 upper leg stumps (92 %) As regards their distribution among the 184 patients the number of unilateral amputees is 149 (81 %) 13 lower leg amputees and 136 upper leg amputees This leaves 35 bilateral amputees (19 %) consisting of 31 with bilateral upper leg stumps and four with one lower leg and one upper leg stumps and totalling 70 stumps 171 amputees (92 %) had a unilateral or bilateral upper leg stump and 13 (8 %) had a unilateral lower leg stump

The mean age of the unilateral lower leg amputees is found to be 64 8 years and that of the unilateral upper leg amputees is 69 8 years, means which do not differ on a statistically significant level The mean age at amputation of the bilateral amputees is 65 8 years against 69 4 years for the unilateral amputees the difference is statistically almost significant ($P < 0\,05$) The time intervening between the amputations on the first amputated leg and on the other in the bilateral cases was 1 1 years on the average

Comparison of the diabetics and non diabetics reveals that of the diabetics 5 have unilateral lower leg stumps (11 %) against 12 (9 %) among the non diabetics The diabetics with bilateral stumps number 8 (18 %), and the non diabetics 27 (19 %) The mean age of the bilateral diabetic amputees is 66 9 years and the average interval between amputations was 1 0 years the corresponding figures for the non diabetics are 65 3 years and 1 2 years The are no statistically significant differences

On comparison of the male and female series the observation can be made that both have unilateral lower leg stumps in equal proportion the women number 5 (7 %) and the men 8 (7 %) Unilateral upper

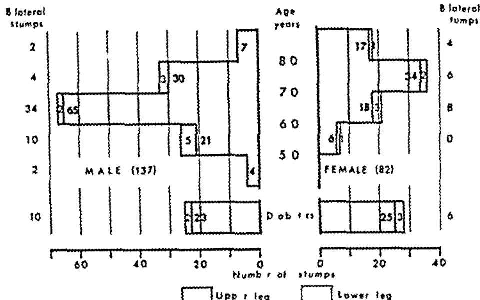


Fig 2 Distribution of the male and female patients upper leg and lower leg stumps resulting from amputation by ten year age groups The male and female diabetics stumps have been separately indicated regardless of age

leg stumps occur in 59 women (81 %) and in 77 men (69 %) while 9 women (12 %) and 26 men (23 %) have bilateral stumps the latter percentages differ at a statistically almost significant level ($P < 0.05$)

Comments on the material

The principle followed in selecting the present material was to include in the series from a 14 year material of amputations at the lower leg or thigh, only those cases in which the amputation had been caused by gangrene or an ischaemic state due to arteriosclerosis

In previously presented even unselected series the majority of the patients were subjected to amputation on account of arteriosclerotic gangrene Such series of cases involving amputation exclusively or mainly on account of arteriosclerosis (Perlow and Roth 1949 McKenzie 1955 Claugus et al 1958 Dale et al 1959 1962 Schlitt and Serlin 1960 Alffram and Holmquist 1961 Perlow 1962 Lindholm 1964a b Hansson 1964) have some common characteristics Nearly all patients are over 50 years old and about half of them are older than 70 the men outnumber the women the women s age at amputation is higher than the men's the age at amputation of diabetics is 5—10 years lower than that of non diabetics and women are about twice as numerously represented among diabetics compared to the non diabetics the number of upper leg stumps

tients received peroral tablet treatment, and the other 14 managed on diet

From Fig 2 the numbers of final lower leg and upper leg stumps and their distribution by sex and age can be seen Moreover the diabetics' stumps have been indicated for all ages in aggregate

The 219 stumps itemized in Fig 2, which belonged to 184 patients, came about as follows Primary lower leg amputation was performed on 24 extremities Nine of them (38 %) had to be re amputated later in two instances at the lower leg and in seven at the thigh The end result was 17 lower leg stumps and seven upper leg stumps Correspondingly primary amputation at the thigh was performed on 195 extremities, of which nine (5 %) had to be subjected to later reamputation The total is thus 219 primary amputations and 18 reamputations (8 %)

The 219 final stumps comprise 17 lower leg stumps (8 %) and 202 upper leg stumps (92 %) As regards their distribution among the 184 patients the number of unilateral amputees is 149 (81 %), 13 lower leg amputees and 136 upper leg amputees This leaves 35 bilateral amputees (19 %) consisting of 31 with bilateral upper leg stumps and four with one lower leg and one upper leg stumps and totalling 70 stumps 171 amputees (92 %) had a unilateral or bilateral upper leg stump and 13 (8 %) had a unilateral lower leg stump

The mean age of the unilateral lower leg amputees is found to be 64 8 years and that of the unilateral upper leg amputees is 69 8 years, means which do not differ on a statistically significant level The mean age at amputation of the bilateral amputees is 65 8 years against 69 4 years for the unilateral amputees the difference is statistically almost significant ($P < 0\ 05$) The time intervening between the amputations on the first amputated leg and on the other in the bilateral cases was 1 1 years on the average

Comparison of the diabetics and non diabetics reveals that of the diabetics 5 have unilateral lower leg stumps (11 %) against 12 (9 %) among the non diabetics The diabetics with bilateral stumps number 8 (18 %), and the non diabetics 27 (19 %) The mean age of the bilateral diabetic amputees is 66 9 years and the average interval between amputations was 1 0 years the corresponding figures for the non diabetics are 65 3 years and 1 2 years The are no statistically significant differences

On comparison of the male and female series the observation can be made that both have unilateral lower leg stumps in equal proportion the women number 5 (7 %) and the men 8 (7 %) Unilateral upper

B Methods of investigation

From the case reports and associated laboratory and X ray examinations and from follow up study the following facts were extracted

1 Previous history

The anamnestic data were collected from a total of 386 case reports in the case of 38 patients they were checked on follow up study Of various clinical symptoms of arterial occlusion the following were noted intermittent claudication angina pectoris cardiac infarction cerebral apoplexy symptoms of occlusion in the region of the neck and shoulders *and angina abdominis In addition to the time of appearance* of the symptoms of occlusion and their duration prior to amputation the number of attacks was also noted in respect of cardiac infarction and apoplexy The time of onset of gangrene was also clarified

2 Local symptoms

The most distal palpable pulse in the lower extremities was noted the extremities were classified on the basis of this finding in very much the same way as Hanley (1955) and Silbert and Zazeela (1958) have done

(a) Pulse of the femoral artery and those distal to it absent
(b) *Pulse of the popliteal artery and those distal to it absent*
(c) Pulses of anterior and posterior tibial arteries absent
(d) One pulse of the foot absent and
(e) All pulses feebly palpable

Furthermore the following subdivision on the basis of ischaemic symptoms was made

(f) Rest pain or continuous pain but no cutaneous lesions and
(g) Gangrene necrosis of skin or ulceration

3 Records of operation

The following were noted from the records made of the operations height of amputation cutaneous subcutaneous and *muscular bleeding* during operation tautness of skin and sutures on closure of the wound and application of a drain

4 Post operative data

The following were noted time of removal of the drain healing of the wound *p p i* tautness of the skin at removal of sutures wound dehiscence on removal of sutures purulent discharge from the wound cellulitis wound haematoma sequesters and febrility

5 Laboratory examinations

From the urine examinations the following were noted proteins sugar specific gravity and sediment From blood tests haemoglobin creatinine and rest nitrogen The urinary examinations were made from morning urine Other examinations evaluated include electrocardiographic studies of which the report of an internal specialist was available in every instance

6 X ray examinations

Existing aortic and lower extremity angiographies were studied and any apparent stenoses and occlusions observed as well as the degree to which the popliteal artery and its branches were visible Furthermore in a manner similar to that applied by Singer (1963) the diameter of the artery was measured from the arteriographs comparing it to normal and classifying on this basis the observed changes according to five degrees of severity as follows 0° substantially normal or atherosclerotic changes without constriction of the lumen 1° lumen constricted to two-thirds of normal, 2° lumen constricted to one-third of normal 3° segmental occlusion completely blocking the lumen and 4° thrombus occluding the entire artery or several separate occlusions

7 Autopsies

The autopsy findings relating to arteriosclerosis have been classified according to three degrees of severity mild moderate and severe Attempts were made to apply the WHO classification principles (Technical Report Ser No 143) In the region of the aorta such changes were considered mild ones in which mainly fatty streaks or fibrous plaques were seen while the changes were considered to be moderate in degree when there were mainly atheroma formations Changes accompanied by haemorrhage thrombus ulcerations or calcium deposits have been denoted as severe changes Such changes elsewhere in the vascular system in which less than one-half of the lumen was intact have been placed in the severe category those with more than one half of the lumen remaining intact being considered moderate changes and the changes with mere fatty streaks or fibrous plaques but no constriction of the lumen belonging to the mild category

8 Follow up study

At follow up examination the above mentioned anamnestic data were checked as well as the existing status and the local symptoms in the

remaining extremity if any The rehabilitation expedients applied and the residual ability to move were also established according to the following categories able to move with prosthesis with crutches wheel chair invalid bed patient The patient s return to work was also recorded as well as his place of residence at home in a home for aged people or in a home for invalids

9 Mathematical methods

Mean values and standard deviations — For the entire series and for subseries consistent with various aspects the mean ages of the patients were computed as arithmetic means mostly also calculating the respective standard deviations The same characteristics were calcu lated for the durations of various symptoms remaining life spans and other similar times but in such instances the usual formulae were applied to the logarithms of the time intervals not the times themselves the better appropriateness of this procedure being clearly indicated by the distributions of individual values

Frequencies and distributions — The frequencies of various symptoms etc as well as distributions e g according to positive or negative find ings were calculated as percentages of the number of patients constituting the subgroup in question

Distribution functions medians — Some series of values were plotted to form cumulative frequency curves in probability chart co ordinates Such curves constituted an aid in determining when the mean formed on a logarithmic basis was more relevant than the arithmetic mean employing the establishment of approximately normal (Gaussian) distri bution as the criterion In some instances the value read from such a plot at 50 % cumulative frequency was then stated as the mean Sometimes the median value of a series was ascertained in addition to the mean obtained in order to confirm the justification of the latter (Cf Fig 5)

Statistical significance tests — The mutual deviations of the means found for different groups were tested for statistically significant differ ences employing Student s t test Comparisons of distribution percent ages were carried out by the aid of the χ test Statistically highly significant significant or almost significant differences have been stated to exist if the probability of the deviation being due to random chance alone is $P < 0\,001$ $0\,01$ or $0\,05$ respectively on the strength of the test

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Comments

Taking into account the age of the patients their fundamental disease and the ailing condition in which they often were on arrival at the hospital one might suspect the anamnestic data at the time of amputation to contain errors and inaccuracies However the possibility of error was lessened by the fact that case reports covering the period prior to amputation were also available for three quarters of all the patients The follow up study revealed in fact that the information obtained from case reports was correct in the case of the 38 persons examined to the extent that the same 44 symptoms of occlusion observed at the time of amputation were also established at follow up and furthermore three additional occurrences of a symptom not stated in the case report

As regards the pulses it can be pointed out as Beckwith et al (1958) and Wylie and Goldman (1958) do that sometimes in the absence of a proximal pulse one distal to it may be palpable indicating good collateral circulation Here however the following rule of thumb (Schoop 1964) has been used if a pulse is absent proximally no pulse can be palpable more distally either and if a pulse is present distally then it cannot be missing more proximally either On this basis the proximal limits of the occlusions have been assessed in the manner in which this was done e g by Juergens et al (1960) and by Holopainen (1963) and classified by types of occlusion (Ratschow 1959) if for instance the popliteal pulse and those distal to it are missing but the pulse of the femoral artery is palpable then it is assumed that the proximal limit of the occlusion lies in the region of the thigh and an occlusion in the femoral region is recorded

Late interpretation of the autopsy findings on the basis of the autopsy report is not as reliable as when the changes are classified immediately at the autopsy but the division into mild moderate and severe changes still furnishes an idea of their degree of severity

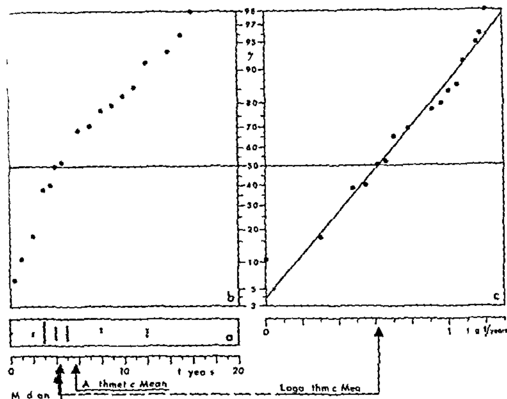


Fig 3 Durations of presence of the intermittent claudication symptom prior to amputation in 48 unilaterally amputated cases presented as an example to illustrate the relevance of mean values obtained by different method

(a) Distribution plot of individual values

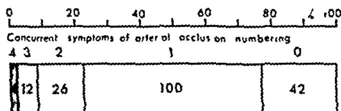
(b) Cumulative percentage of cases plotted on a probability (or normal distribution) chart having an ordinate scale consistent with the probability integral $\frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2} dt$ and with the durations t for abscissae

(c) As (b) but with log t for abscissae

In distinct contrast to graph (b) graph (c) indicates fairly good consistency with normal (Gaussian) distribution Accordingly the logarithmic mean relevantly reflects the probable average (fifty fifty chance) duration of the symptom in an arbitrary comparable population. Its value (4 15 years) agrees in fact closely with the median (about 4 25 years) of the serie The arithmetic mean (5 85 years) considerably exaggerates the duration owing to undue influence exerted by a few large value (up to 20 years) From the distribution graphs the duration of 5 85 years is seen to be one that was surpassed in only one third of the cases

The absence of the intermittent claudication symptom is by no means always a sign of the absence of occlusions in the lower extremity arteries since this symptom does not manifest itself in the event of adequate collateral circulation (Widmer 1965) Another reason for intermittent claudication often failing to be apparent even though there may be several occlusions is the lack of activity of older persons Older people may therefore become victims of gangrene quite unexpectedly (Weibel 1965) The symptom is also somewhat less common in diabetics than in non diabetics (Schadt et al 1961) Heine et al (1965) found that in gangrenous patients the claudication symptom had been present for three years on an average prior to the appearance of gangrene

The occlusions of the lower extremity arteries are quite often nearly symmetric According to Hasse (1959) two years after the onset of intermittent claudication the symptom has become bilateral in 76 % and after five years in 92 2 % of the affected persons Judmaister (1958) reports that the affection becomes bilateral in 75 % within 4—5 years



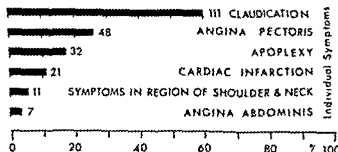


Fig 4 Distribution of the series of 184 patients according to occurrence of 0 1 2 3 or 4 different symptoms of arterial occlusion in their case history (prior to amputation) and frequencies of occurrence in the histories of six different types of symptom

IV CLINICAL SYMPTOMS OF OCCLUSION PRIOR TO AMPUTATION

A general survey of the occurrence of clinical symptoms of occlusion prior to amputation in the present series of 184 patients is presented in Fig 4 One or several such symptoms were present in 142 patients (77 %) The commonest symptom was intermittent claudication which occurred in 60 % of the cases while of those listed here, intestinal symptoms suggesting angina abdominis were the most rarely encountered (in 4 %)

Each symptom of occlusion will be scrutinized by itself considering its distribution by age and sex and comparing the percentages, in the group presenting this particular symptom and in its complementary group of the sexes of diabetics of hypertonics of persons over 70 years in age and of the other groups of symptoms of occlusion For each such subseries characterized by the presence of a given symptom, and for its complementary series the mean ages at the time of amputation have moreover been computed and mutually compared (Table 1)

A Intermittent claudication

Previous investigations

Intermittent claudication is the commonest symptom of occlusion occurring in association with arteriosclerosis According to Ratschow (1959) it is present in a great majority (90 %) of patients with ischaemia of the lower extremities and according to Wanke (1955) its cause is invariably arterial occlusion which occurs in the region of the thigh in 65 % Depending on the height of occlusion intermittent claudication pain is experienced at different heights in the extremity (Leriche 1955 Wolfe et al 1954 Ratschow 1959) but the extent and number of the occlusions and the possible existence of collateral paths also have an influence of their own on this (Beckwith et al 1958 Allen et al 1959)

Commonest among other symptoms of occlusion in association with intermittent claudication is angina pectoris which McDonald (1955) observed in 29 % of the persons suffering from the former it appeared later than the intermittent claudication symptom in most instances

Present studies

Fig 5 shows the occurrence of intermittent claudication in the present series separately for men and for women and also for each ten year age group of both The symptom was present prior to amputation in 111 of the 184 patients (60 %) and had persisted for 2 7 years on an average by the time of amputation It was then bilateral in 88 patients (79 %) The diagram shows that the symptom was commoner in the younger than in the older age groups in men as well as women The percentage of patients with intermittent claudication is seen to diminish more markedly with increasing age in the female subseries than in the male It was present in 17 women over 70 years of age (34 % of all women over 70) and in 25 men (66 %) older than 70 while the corresponding figures for men and women under 70 years are 56 (77 %) and 13 (54 %) respectively the differences between these percentages are statistically *significant* ($P < 0\,01$)

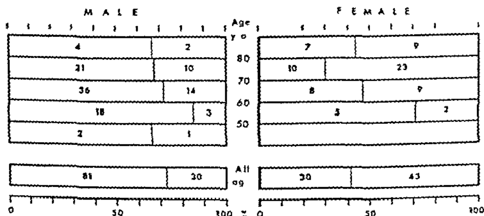


Fig 5 Presence (shaded areas) and absence of the intermittent claudication symptom in the case histories of the male and female patients and of their different ten year age groups

Table 1 contains various data concerning the group of patients with intermittent claudication, which can be compared to the corresponding data for the entire series in the last column of the table. They have also been compared to the respective values found for the complementary group (patients without intermittent claudication preceding amputation).

It is seen that 73 % of the patients with intermittent claudication are men; this differs at a statistically highly significant level ($P < 0.001$) from the percentage of men in the non-claudication group (41 %). The percentage of patients older than 70 years is only 38 % in the intermittent claudication group (statistically significant difference, $P < 0.01$, from the percentage in the complementary group 60 %). As can be expected, the mean age at amputation in the claudication group, 67.1 years, is lower than the mean for the entire series; it differs at a statistically highly significant level ($P < 0.001$) from the mean age 70.8 years of the non-claudication group. Diabetes seems to occur less frequently, hypertonia and angina pectoris and apoplexy more frequently in the group of patients with intermittent claudication than among those without this symptom, but there are no statistically significant differences.

Comments

The intermittent claudication symptom is seen to have been present in 60 % of the patients in this series. In the literature no reference could be found concerning the commonness of this symptom in amputation series, but a somewhat higher frequency is stated for it among patients suffering from arteriosclerosis obliterans. Juergens et al. (1960) in a series of 520 such patients observed the occurrence of intermittent claudication in 73 %. The patients were all male and there were no diabetics. In the present series again, about three quarters of those with the claudication symptom are men, while those lacking the symptom were older persons, predominantly (60 %) women, and nearly one third of them diabetic. It is just in such older persons that the claudication symptom has often been noted to be absent, owing to their inactivity and to the presence of diabetes.

The time prior to amputation during which the intermittent claudication symptom was present averaged 2.7 years and by the time of amputation it had become bilateral in 80 %, consistent with previous observations on claudicated patients. The duration, too, is virtually equal

to the time of three years noted by Heine et al (1964) in gangrenous persons prior to manifestation of gangrene

As with lower extremity occlusion patients in general the occlusions causing claudication in the present series developed not only more frequently but also earlier in men than in women Occurrence of this symptom also implied amputation at an earlier age than in the complementary group the difference about 3 7 years is statistically highly significant ($P < 0.001$)

The frequency at which angina pectoris occurred in association with the intermittent claudication symptom agrees with the frequencies stated for claudication and amputation series in general

B *Angina pectoris and cardiac infarction*

Previous investigations

Sclerosis of the coronary arteries and the resulting ischaemic symptoms develop earlier *in men than in women Oliver and Boyd (1951) in a series* of 1000 patients found for the proportion of men to women the ratio of 2 1 in the 60—69 year age group and 1 1 for those over 70 For cardiac infarctions Zimmermann et al (1954) obtained male/female ratios of 2 2 1 and 1 5 1 with patients under and over 65 years respectively From Sipila s (1966) series the corresponding ratios of 2 75 1 and 0 82 1 can be calculated In women infarction does not begin to occur more commonly until they have reached about 60 years (Walker et al 1956) In Sipila s (1966) series the proportion of men and women over 60 years with *infarction is 1 1 1 and that of patients younger than 60 years* 4 5 1 Branwood and Montgomery (1956) observe that infarction occurs most numerously in young and middle aged men and in older women whose atheromata they report to be soft and conducive to thrombosis

Hypertonia increases the atherosclerosis of the coronary vessels and the resultant ischaemic symptoms (Clawson and Bell 1949 Corcoran et al 1956 Dawler 1964) as does diabetes also (Joslin 1952)

Those suffering from peripheral arterial occlusion disease present symptoms of the coronaries in 12—37 % according to various studies (Spandling 1956 21 % *Juergens et al 1960 16 %* *Singer and Rob* 1960 22—37 % Schadt et al 1961 11 7—26 6 %) and Schlitt and

pectoris and cardiac infarction groups is found to be lower than in the complementary groups by 1 7 and 1 8 years on the average but there is no statistically significant difference

Comments

In the present series angina pectoris occurred prior to amputation in one in every four patients and cardiac infarction in about one in every ten coronary symptoms of one or both kinds were present in somewhat more than one quarter (28 %) of the series This amounts to higher incidences than are encountered in persons of equivalent age suffering from peripheral arteriosclerotic occlusion diseases The percentage found for cardiac infarction is about the same as that observed by Heine et al (1965) in gangrenous patients Hansson (1964) states that he found among 256 arteriosclerotic patients cardiac distress' in 54 % the occurrence of coronary symptoms in the present series thus agrees rather closely with that in his material

In the present series angina pectoris and cardiac infarction both occurred in nearly equal percentages of men and women However coronary arteriosclerosis and its attendant ischaemic symptoms developed earlier in men than in women Here too angina pectoris and cardiac infarction were encountered in men upwards of ages under 50 years while they only occurred in women subjected to amputation at ages of 60 years or older The majority of female cases with cardiac infarction (90 %) were found in the group of patients over 70 years at amputation whereas of the men only one in every five (18 %) presenting cardiac infarction belongs to this age group

Roberts et al (1959) observed that the degree of severity of occlusions of the coronary arteries also reflects the changes present elsewhere in the vascular system More serious obliteration of the vessels of the lower extremities in the patients having coronary symptoms as compared to those lacking such symptoms is suggested in the present series by the fact that the claudication symptom and angina abdominis also was more frequent in the group of patients with angina pectoris than in its complementary group The age at amputation, which was 1 7—1 8 years lower than in the group without coronary symptoms, is also indicative of the earlier development of the occlusions

C Cerebral apoplexy

Previous investigations

Concerning the genesis of cerebral ischaemic states Millikan (1965) says that atherosclerosis is usually accompanied by some transient pathophysiological condition but that such conditions rarely appear without atherosclerotic lesion

According to Senn (1965) the seriousness of the clinical picture and the pathological finding are often but not always correlated thus in complete hemiplegias occlusion of the internal carotid artery is often present and in smaller fits vascular stenosis Investigations have pointed out with increasing insistence the considerable contribution of extracerebral arterial occlusions to the genesis of cerebral ischaemic symptoms and on the other hand the commonness of asymptomatic occlusions (Hutchinson and Yates 1957 Martin et al 1960 Schwartz and Mitchell 1961) In an amputation series consisting of arteriosclerotic patients Hansson (1964) found 11 4 % to have had a cerebral apoplexy prior to amputation

Present Studies

Fig 8 shows the preamputation occurrence of apoplexy in the present series separately for men and women and for their different ten year age groups

Altogether 32 patients (17 %) had suffered from apoplexy prior to amputation but had recovered to such an extent that all but one of them were able to move at the time of amputation In three patients subjected to amputation at ages over 70 years apoplexy had occurred twice and one man who was 66 years at the time of amputation had had three strokes The men and women with a history of apoplexy number 18 and 14 respectively (16 % of all men and 19 % of all women) no statistically significant difference being established in this respect The time when apoplexy had occurred was on the average 1 4 years before amputation It can be seen in Fig 8 that all the women with a history of apoplexy were older than 60 years at the time of amputation of the corresponding group of men only two were younger than 60 The percentages of women with previous apoplectic fits decrease with increasing age but numerically most of them belong to the age group of 70—79 years The

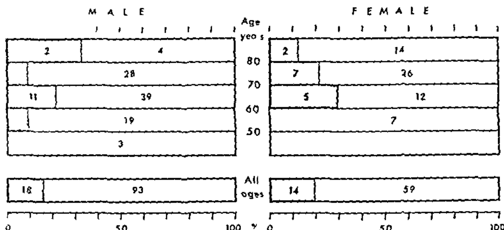


Fig. 8. Presence (shaded areas) and absence of apoplexy in the case histories of the male and female patients and of their different ten-year age groups.

men with previous apoplexy display a non-uniform age group distribution, the greatest number of such cases is found among those subjected to amputation at the age of 60—69 years. The mean age of those with apoplexy prior to amputation is 68.5 years in the men's series and 70.9 in the women's; the combined mean age is 69.5 years.

Table 1 (p. 28) enables various data concerning the patients of the apoplexy group to be compared with the complementary group. The apoplexy group is found to contain relatively more women, more hypertonics and more patients with previous claudication and angina pectoris symptoms than the complementary group in which no apoplexy occurred, but there are no statistically significant differences.

Comments

In Hansson's (1964) series about one in every nine of 236 patients subjected to amputation on account of arteriosclerosis had previously suffered from apoplexy. In the present series apoplexy occurred somewhat more frequently, in one out of every six patients, and clearly more often than was observed by Widmer (1963) in patients with occlusion in the lower extremities. There seems to be no relationship between the degrees of severity of sclerosis in the lower extremities and that of the cerebral arteries (Roberts et al. 1959). In the present series, too, no correlation of the development of occlusions impairing cerebral circulation in arteriosclerosis elsewhere in the vascular system can be noted.

no essential deviations are observable between the apoplexy group and its complementary group in the occurrence of other symptoms of occlusion It is also to be noted that the age at amputation is one year higher in the apoplexy group than in that without apoplexy suggesting that in the former the changes resulting in gangrene evolved some what later although there is no statistically significant difference

D Symptoms of occlusion in neck, region of the shoulders and upper extremity

Previous investigations

In the symptoms of occlusion in the neck and shoulder region Ratschow (1959) includes those due to obliterations of the aortic arch carotid arteries and subclavian artery Symptoms of occlusion of the aortic arch have been described under synonymous names e g by Martorell and Fabre (1944) Frovig and Loken (1951) Ross and McKusick (1953) and Tala (1966) From the diagnostic point of view the optic and cerebral symptoms are most notable among the symptoms of occlusion of the aortic arch and carotid arteries (Ratschow 1959 Mumenthaler 1965)

Circulatory disturbances due to arterial occlusions in the upper extremities are often rather inconspicuous For instance Kappert (1964) says that complete occlusion of the brachiocephalic trunk or subclavian artery causes functional derangement in only one half of the cases

Ratschow estimates that at least about 2 % of those suffering from arterial occlusion have occlusions in the region of the upper extremities In mass examinations Widmar et al (1965) found for the upper extremities a share of about 14 % in the observed extremity occlusions but about two thirds of them were asymptomatic at the first enquiry

Present studies

Symptoms indicative of occlusion in the neck and shoulder region other than of the apoplexy type were present prior to amputation in 10 patients (5 % of the entire series) four women and six men (Table 1) The duration of the symptom was known with any greater accuracy in two cases only (1 5 and 2 years respectively) The mean age of the

women with this symptom was 74 5 and that of the men was 63 3 years the mean age of all ten patients being 67 7 years

Six of these patients complained of rapid tiring and coldness of one upper extremity Four patients had cerebral symptoms or optic disturbances but no previous apoplexy or epilepsy had been established After amputation however three of these four suffered from apoplexy Two of the four patients had brief spells of unconsciousness Two patients had attacks of vertigo and one of these moreover, optic disturbances which were attributed to disturbance of circulation

Comments

Symptoms of occlusion from the upper extremities were recorded in comparatively few instances in the present series (3 %) and the symptoms were fairly slight The frequency of occurrence agrees in order of magnitude with previous findings concerning arterial occlusion patients Cerebral symptoms suggesting arterial stenosis or occlusion partly of little stroke type were noted in four cases (2 %) prior to amputation Three of these patients suffered apoplexy later Nothing can be stated on the strength of the symptoms observed here as regards the extent and location of the potential occlusions To make this possible thoracal arteriographs would have to be available as e g Fuchs (1965) and Mumenthaler (1965) point out this is the sole method of examination furnishing any idea of the pathological changes and topographic anatomical state of the blood vessels in the region of the aortic arch

E Angina abdominis

Previous investigations

Angina abdominis or intermittent mesenteric claudication' as it was called by Klein (1921), is a rarely diagnosed disease Owing to the good collateral circulation in the intestines stenosis of one main artery of the bowels does not usually suffice to produce the symptoms what is needed is functionally significant stenosis in two of the three arteries the superior mesenteric the inferior mesenteric and the coeliac artery or complete occlusion of one main artery (Rob 1965 Schobinger 1965) The symptom is commonest in the sixth to eighth decades but as a

result of the rare occurrence of the typical angina abdominis symptom larger series are lacking (Schobinger 1965) as well as more detailed information on its commonness Possibilities to be eliminated in differential diagnosis include cholecystitis duodenal stomach ulcer pancreatitis and tumours in the abdominal region (Chinaglia 1964)

Present studies

Symptoms indicative of angina abdominis were present prior to amputation in seven patients (4 %) three men and four women (Table 1) In two cases (1 % of the entire series) angina abdominis had been diagnosed the other five patients had typical pain and displayed loss of weight without any other disease in the abdominal region having been established In one of the two patients with angina abdominis symptoms these symptoms had appeared 0 5 years before amputation there are no data on the duration of the disease in the other instances The mean age of the men concerned here was 66 4 years that of the women was 68 8 years and the mean of all seven was 67 6 years Owing to the small number of cases the data concerning the group of amputees with previous angina abdominis symptoms entered in Table 1 permit at the most the observation to be made that this group displays a tendency towards a higher frequency of other symptoms of occlusion in comparison to its complementary group

Comments

The angina abdominis symptom is a rare one Here too it was only observed in two patients while five other patients had symptoms indicating chronic circulatory insufficiency of the bowels

F Concurrence of symptoms of occlusion

Previous investigations

According to Widmer (1963) arteriosclerotic changes in the extremities suggest diffuse arterial disease and he observed that of 64 patients with occlusion of the extremity arteries, one tenth had suffered apoplexy and about one third had a coronary disease He says as do also Dawber et al (1957) that arterial occlusions of the extremities and coronary

diseases begin to appear at about the same time and that they occur in an equal amount Hansson (1964) states that multiple manifestations of vascular diseases occurred in 44 8—37 6 % of 236 persons subjected to amputation on account of arteriosclerosis Even if there are occlusions, they may remain asymptomatic in the region of the lower extremities owing for example to lack of activity (Widmer 1963, Weibel 1965)

Present studies

The frequency at which one or several symptoms of occlusion occurred prior to amputation in the present series is elucidated by the figures in Table 2 (also shown in Fig 4, p 27) It can be seen that symptoms of occlusion were present in about three quarters of the patients Of the six individual symptoms considered angina pectoris and cardiac infarction have been treated here as only one symptom since all but three of the patients with cardiac infarction had also displayed the angina pectoris symptom Two or more symptoms of occlusion occurred in about one quarter of the series three or more symptoms occurred simultaneously *even more rarely (in 9 %), and only four patients displayed simultaneous symptoms suggestive of four different symptoms of occlusion*

Table 2 Presence of one or more symptoms of arterial occlusion in the case histories of 184 patients

Number of concurrent symptoms of arterial occlusion	Cases	Per cent
4	4	2
3 or more	16	9
2 or more	42	23
One or more	142	77
None	42	23

The data compiled in Table 1 (p 28) for the patients having more than one symptom of occlusion show that this group contains a distinctly higher proportion of patients with coronary symptoms and also with intermittent claudication symptoms than its complementary group the difference is statistically highly significant ($P < 0\,001$) in both respects *The same trend observable with regard to apoplexy and to the angina*

abdominis symptom does not produce any statistically significant differences. The frequency of symptoms of occlusion in the region of the neck and shoulders is higher at a statistically almost significant level ($P < 0.05$).

The group of patients who had no symptoms of occlusion prior to amputation, also similarly tabulated in Table 1, contains proportionately more women than its complementary group and the mean age at amputation is 4.2 years higher. The former difference is statistically significant ($P < 0.01$) and the latter is statistically almost significant ($P < 0.05$).

Comments

Hansson's (1964) series of amputees showed multiple manifestations of arterial occlusion in an average number equivalent to 42 %. In the present series the proportion is the same (45 %) if the ischaemic state of the extremity leading to amputation is counted as one type of manifestation. If only intermittent claudication and other symptoms of occlusion occurring prior to amputation are taken into account, the manifestations of arteriosclerosis producing multiple symptoms amount to slightly more than one quarter (28 %). Correlation exists between the arteriosclerotic changes in the coronary arteries and those in the arteries of the lower extremities (Dawber et al. 1957, Roberts et al. 1959, Widmer 1963). In the present series, too, symptoms of occlusion of the coronary and lower extremity arteries could be noted as occurring concurrently in the same patients in the group of amputees with two or more symptoms of occlusion at a frequency higher than in the complementary group, at a statistically highly significant level ($P < 0.001$). No such trend concerning the claudication symptom is displayed by the patients who suffered apoplexy. Symptoms of occlusion were more numerous in men than in women and amputation occurred on the average 4.2 years earlier in those with symptoms of occlusion than in those having none.

V THE SPREAD OF ARTERIOSCLEROTIC CHANGES AT THE TIME OF AMPUTATION

In the reports on examinations at the time of amputation, results have been included of those examinations made within two weeks before and after the amputation Such examinations were pulse examinations of the extremities measurements of blood pressure angiographies, electro cardiographic studies Results of laboratory tests were also included urine examinations and determinations of blood urea and creatinine These examinations have been evaluated in an attempt to obtain an idea of the extent of the spread of the arteriosclerosis at the time of amputation

A Extremity pulses

Previous investigations

In Schoop s (1964) opinion palpation of the arterial pulse is the most important method in examining arterial occlusion diseases But this does not reveal the extent nor the number of occlusions, although it is true that an idea is gained of their localization and proximal limit (Ratschow 1959 Juergens 1960) This constitutes for instance the basis of Ratschow s (1959) classification of occlusion types by the localization of the occlusions

The commonest state of the lower extremities in peripheral arterial occlusion diseases is that the pulse of the femoral artery is palpable but not that of the popliteal artery, in which case there is an occlusion in the femoral region Wanke (1959) found such occlusions in the femoral region in 65 % of 371 patients with peripheral arterial occlusion, Hasse (1950) state a corresponding percentage of 47 6 % and Heine et al (1965) one of 51 2 % for gangrenous patients Patients of the latter category have often according to Heine et al in 48 7 %, occlusions both

in the femoral and in the lower leg regions although the occlusion in the lower leg cannot be discovered by pulse examination (Schoop 1964) Occlusions in the femoral region often turn into occlusions in the pelvic region owing to thrombosis in which instance the prognosis becomes unfavourable (Leriche 1955 Ratschow 1959 Wanke 1959)

According to Ratschow (1959) only about 2 % of the persons suffering from arterial occlusion disease have occlusions in their upper extremities and can thus be expected to display pulse changes in that region Widmer (1963) says that occlusions in the region of the upper extremities occur in about one seventh of the patients with extremity occlusions but that they are usually adequately compensated and so are more seldom clinically manifest

Present studies

The diagram in Fig 9 gives a synopsis of the findings at the time of the first (or only) amputation concerning pulses and the ischaemic state of both extremities i e the extremity amputated at that time and the one remaining intact permanently or until further amputation The most notable differences between the extremity subjected to amputation (A) and the extremity remaining intact (B) are noted in the most proximal and most distal pulses On the side on which amputation was performed the pulse of the femoral artery was absent in 63 cases (35 %) against 21 cases (13 %) on the other side thus is a statistically highly significant difference ($P < 0\,001$) All pulses were palpable on the amputation side in only three cases (2 %) against 32 cases (21 %) on the side left intact which amounts to a statistically highly significant difference ($P < 0\,001$) too One of the two pulses of the foot could be palpated in only four cases (2 %) on the amputated side but in 23 (14 %) on the other The popliteal pulse was absent in the first amputated and intact extremities in 64 and 54 cases (36 and 33 %) respectively the pulses of the anterior and posterior tibial arteries were both absent in 44 and 32 cases (25 and 20 %) in the respective extremities No statistically significant differences were established from these latter comparisons

At the time of the first amputation gangrene was present in the extremity subjected to amputation in 152 cases (84 %) and rest pain in 28 cases (16 %) The corresponding figures for the extremity left intact at this stage are 26 (15 %) and 3 (2 %) Gangrene had set in on the average 3 months before amputation All the 29 last mentioned cases

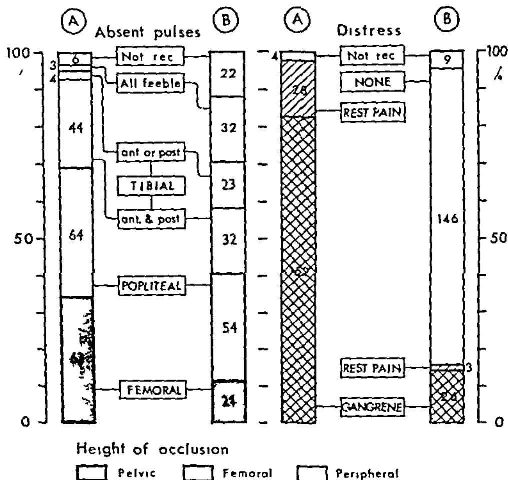


Fig 9 *Left* Distribution of 184 patients according to non palpability of different pulses and type of occlusion consistent with these findings in the amputated extremity (A) and in the extremity left intact (B) at the time of the first (or only) amputation

Right Distribution of 184 patients according to ischaemic condition of the amputated extremity (A) and the extremity left intact (B) at the time of the first (or only) amputation

and another six cases in which no gangrene or rest pain was yet present in the other extremity at the time of the first amputation had to be subjected to bilateral amputation later

In Table 3 the cases of the present series have been arranged according to types of occlusion taking into account the pulse findings in both extremities at the time of the first amputation In this representation the lowest diagonal gives the numbers of cases displaying symmetric occlusion in both extremities at various heights The cases with sym-

metrical occlusion amount to 47 % of the men and 35 % of the women and 41 % of the entire series There is no statistically significant difference between men and women Nearly symmetrical conditions which include e g occlusion in the femoral region on one side and in the pelvic region on the other were present in 30 % of all cases without any statistically significant difference between men and women In the diabetics symmetrical states were more frequent than among the non diabetics (50 and 36 % respectively) at a statistically almost significant level ($P < 0.05$)

Table 3 Percentages of different combinations of types of occlusion present on both sides in the entire series of 184 patients and in the male female diabetic and non-diabetic subseries

Type of occlusion	Pelvic	Femoral	Peripheral	All pulses feeble	Not rec	Pelvic	Femoral	Peripheral	All pulses feeble	Not rec
ENTIRE SERIES 184 patients										
Pelvic	10	13	5	4	3					
Femoral		15	9	7	3					
Peripheral			15	8	2					
All pulses feeble				1	–					
Not recorded					4					
MEN 111 patients						WOMEN 73 patients				
Pelvic	14	16	6	4	3	4	10	4	6	3
Femoral		14	7	5	3		19	13	10	4
Peripheral			18	7	1			1[illegible]	8	4
All pulses feeble				1	–				–	–
Not recorded					3					3
DIABETICS 45 patients						NON DIABETICS 139 patients				
Pelvic	4	7	2		–	12	16	7	4	4
Femoral		13	4	2	2		13	11	8	4
Peripheral			31	16	4			11	5	1
All pulses feeble				2	–				–	–
Not recorded					5					2

As regards the distribution of different types of occlusion among men and women there is a statistically almost significant difference ($P < 0.05$) in the number of occlusions of the pelvic region between men and women but no other differences of a statistically significant level can

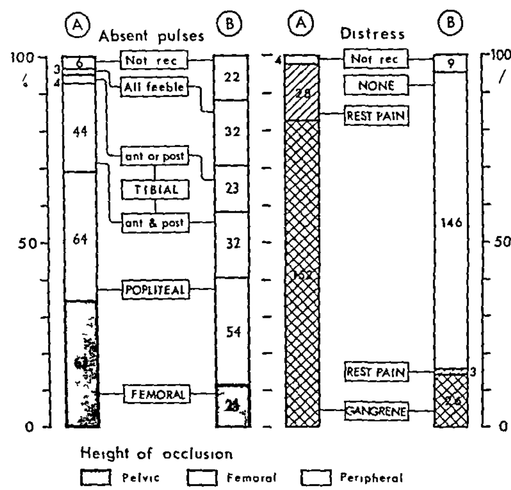


Fig 9 *Left* Di tribution of 184 patients according to non palpabilit of different pul es and type of occlusion con istent ith the e findings in the amputated extremity (A) and in the extremity left intact (B) at the time of the first (or only) amputation

Right Di tribution of 184 patients according to i chaemic condition of the amputated extremity (A) and the extremity left intact (B) at the time of the first (or only) amputation

and another six cases in which no gangrene or rest pain was yet present in the other extremity at the time of the first amputation, had to be subjected to bilateral amputation later

In Table 5 the cases of the present series have been arranged according to types of occlusion taking into account the pulse findings in both extremities at the time of the first amputation In this representation the lowest diagonal gives the numbers of cases displaying symmetric occlusion in both extremities at various heights The cases with sym

metrical occlusion amount to 47 % of the men and 35 % of the women and 41 % of the entire series There is no statistically significant difference between men and women Nearly symmetrical conditions which include e g, occlusion in the femoral region on one side and in the pelvic region on the other were present in 50 % of all cases without any statistically significant difference between men and women In the diabetics symmetrical states were more frequent than among the non diabetics (50 and 56 %, respectively) at a statistically almost significant level ($P < 0.05$)

Table 3 Percentages of different combinations of types of occlusion present on both sides in the entire series of 184 patients and in the male female diabetic and non-diabetic sub series

Type of *occlusion*	Pelvic	Femoral	Peripheral	All pulses feeble	Not rec	Pelvic	Femoral	Peripheral	All pulses feeble	Not rec
ENTIRE SERIES 184 patients										
Pelvic	10	13	5	4	3					
Femoral		15	9	7	3					
Peripheral			15	8	2					
All pulses feeble				1	–					
Not recorded					4					
MEN 111 patients						WOMEN 73 patients				
Pelvic	14	16	6	4	3	4	10	4	6	3
Femoral		14	7	5	3		19	13	10	4
Peripheral			18	7	1			12	8	4
All pulses feeble				1	–				–	–
Not recorded					3					3
DIABETICS 45 patients						NON DIABETICS 139 patients				
Pelvic	4	7	2	7	–	12	16	7	4	4
Femoral		13	4	2	2		13	11	8	4
Peripheral			31	16	4			11	5	1
All pulses feeble				2	–				–	–
Not recorded					5					2

As regards the distribution of different types of occlusion among men and women there is a statistically almost significant difference ($P < 0.05$) in the number of occlusions of the pelvic region between men and women, but no other differences of a statistically significant level can

be noted Diabetics on the other hand, displayed the symmetrical peripheral type of occlusion more frequently than the non diabetics (31 and 11 % respectively) at a statistically highly significant level ($P < 0.001$) and the type with peripheral occlusion on one side and all pulses feebly palpable on the other is also more numerous than in the non diabetic group, at a statistically almost significant level ($P < 0.05$) The combination of pelvic occlusion on one side and femoral occlusion on the other occurred less often than among the non diabetics at a statistically almost significant level ($P < 0.05$)

The pulses have further been tabulated in Table 4 by pulse types in the light of the findings in the first amputated extremity and the extremity left intact, at the time of amputation and at that of preceding sympathectomy The intervals between sympathectomy and amputation averaged 0.36 years Pelvic, femoral and peripheral occlusions are seen to have been almost equally frequent at the time of amputation in the amputated extremities Comparison of the amputated and intact extremities reveals that the pelvic type of occlusion occurred more often in the amputated than in the intact extremities at a statistically almost significant level ($P < 0.05$) Palpability of all pulses was recorded more frequently in the latter extremities at a statistically significant level ($P < 0.01$)

In Table 4 from the distribution by type of occlusion at the time of sympathectomy and at amputation, the observation can be made that during the intervening time of 0.36 years on the average, the occlusions of the pelvic region more than doubled in frequency on the amputated

Table 4 Types of occlusion according to palpation of pulses at the time of sympathectomy *and of amputation in the amputated extremity and in the extremity left intact*

Type of arterial occlusion	At the time of sympathectomy		At the time of amputation			
			Amputated extremities		Intact extremities	
	Amputated extremities	Intact extremities	All cases	Sympathectomized	All cases	Sympathectomized
Pelvic region	11 *20 %*	–	73 *35 %*	29 *46 %*	11 *8 %*	2 *13 %*
Femoral region	24 *45 %*	5 *33 %*	79 *38 %*	21 *33 %*	39 *30 %*	4 *27 %*
Peripheral	15 *28 %*	9 *60 %*	55 *26 %*	11 *18 %*	48 *37 %*	8 *53 %*
All pulses feeble	4 *[illegible] %*	1 *7 %*	3 *1 %*	2 *3 %*	33 *25 %*	1 *7 %*
	54 *100 %*	15 *100 %*	210 *100 %*	63 *100 %*	131 *100 %*	15 *100 %*
Not recorded	9		9		18	

Table 5 Changes in the arteries of the pelvic region and lower extremities revealed by 21 arteriographies in per cent of cases examined

Part of arterial tree (a) – on amputated side (b) – on side left intact		Number of arteries examined	Degree of severity of change					Entirely or partly patent lumen	Complete occlusion
			0	1	2	3	4	(0 to 2)	(3 or 4)
Aorta		14	43	36	14	7	–	93	7
Iliac artery									
– common	(a)	14	14	14	7	7	57	36	64
	(b)	14	14	50	14	7	14	79	21
– external	(a)	14	7	29	7	14	43	43	57
	(b)	14	14	21	29	7	29	64	36
– internal	(a)	14	21	14	14	21	29	50	50
	(b)	14	36	21	14	21	7	71	29
Total	(a)	42	14	19	10	14	43	43	57
	(b)	42	21	31	13	12	17	1	29
Femoral artery									
– common	(a)	14	50	14	14	7	14	9	21
	(b)	14	50	21	7	14	7	79	21
– superficial	(a)	16	–	14	7	14	64	21	79
	(b)	14	14	29	14	7	36	57	43
– deep	(a)	16	50	29	7	7	7	86	14
	(b)	16	72	14	14	–	–	100	–
Total	(a)	46	33	19	10	10	9	62	38
	(b)	44	45	21	12	7	14	9	21
Popliteal artery									
	(a)	14	[illegible]	43	14	7	29	64	36
	(b)	6	50	50	–	–	–	100	–

sufficiently visible in the arteriograph to enable the degree of severity of its changes to be determined The distributions have been stated as percentages of the total number of subjects assessed for the artery concerned

The abdominal aorta was visible in its entirety in the lumbar arteriograph in three cases only while in the others usually only its lower third appeared in the X ray In this region only one total occlusion (7 % of the cases) about 1 cm in length was noted immediately above the bifurcation continuing into both common iliac arteries The number of normal findings amounts to 43 %

Disregarding the abdominal aorta, which was only partly examined the smallest changes were observed in the region of the deep femoral artery total occlusion occurred in 14 %, while this artery was normal in half of the cases In the intact extremity no total occlusions were seen and the finding was normal in 72 %

Occlusions occurred most profusely in the region of the superficial femoral artery on the amputated side there were total occlusions in 79 % and the normal findings were nil the side of the intact extremity presented total occlusions in 43 % and a normal condition in only two cases (14 %) In the iliac arteries total occlusion was established on the amputated side in more than one half (57 %) and normal status in 14 % only on the other side in 29 and 21 % respectively The occlusions in the popliteal artery on the amputated side amounted to 36 % with only 7 % normal the other side presented no total occlusions at all and a normal condition in one half of the subjects

In 14 arteriographs of the amputated extremity all three branches of the popliteal artery were made visible in three instances two branches in five and one branch or none in three instances Of the six arteriographs of the intact extremity two were such in which all branches of the popliteal artery were visible while two branches could be seen in the other four

The most notable difference between the amputated extremity and that left intact at the amputation is that concerning occlusions of 4°, they occurred 2—4 times as frequently on the amputated side as on the other side With regard to the combined number of occlusions of the iliac arteries this produced a statistically significant difference ($P <$ 0 01) whereas no difference on a statistically significant level exists in respect of the combined occlusion in the femoral arteries

Comments

Among the occlusions of major arteries in the pelvis and lower extremities those in the region of the superficial femoral artery have proved to be commonest In the present study too occlusion in this region was most frequently present occurring on the amputated side in about three quarters and on the side of the non amputated extremity in nearly one half of the cases examined

Obliterations were less often encountered in the region of the deep femoral artery which presented a normal condition on the amputated side in 50 % and on the other side in 72 % consistent with the percentage of 72 % observed by Singer (1963) for patients with ischaemia of the lower extremities There were no total occlusions on the side of the intact extremity and even on the amputated side they only occurred in about one out of every seven patients

Commonest among the occlusions in the pelvic region was that in the region of the common iliac artery occurring in two thirds and in about one fifth of the cases on the amputated and intact side respectively Singer observed in patients with intermittent claudication occlusion in a corresponding area in about 50 % The common femoral artery and popliteal artery too had been fairly well preserved on the non amputated side so that about one half of them were normal

On the whole the number of changes noted on the non amputated side was consistent with that observed by Singer (1963) for example in 205 arteriographs of ischaemic patients whereas they were more frequent on the amputated side The most notable difference concerns occlusions covering the entire length of an artery or multiple occlusions These are more numerous on the amputated side than on the opposite side by a factor of about 2—4 The difference is statistically significan ($P < 0.01$) in respect of the total numbers of occlusions in the iliac arteries

C Electrocardiographic studies

Previous investigations

Coronary sclerosis or coronary insufficiency cannot be diagnosed on the basis of the ECG alone without knowledge of the clinical picture because similar ECG changes are produced by many other factors including metabolic disturbances disturbances of liquid balance and digitalization (Hauss 1954 Holzmann 1960 Schettler 1961)

On the other hand clinical findings indicative of changes in the coronary arteries do not necessarily imply changes in the ECG. Cardiologists have thus established for instance in angina pectoris a normal ECG in 25—40 % of the cases (Rinzler 1957, Schettler 1961). The information furnished by the ECG is thus not unambiguous and ECG diagnostics may be comparatively problematic. In the opinion adopted by the World Health Organisation (1959), only ECG changes indicating cardiac infarction possess actual value as evidence. In patients with arterial occlusion ECG changes are fairly common. Hasse (1959) gives their percentage as 42.8 % and Beckwith et al. (1958) as 65 %. Singer et al. (1960) observed signs of previous ischaemic heart disease in 24 % of 219 patients with intermittent claudication.

Present studies

At the time of amputation the ECG was taken of 87 patients. Changes were observed in 60 of them (69 %) Table 6. Changes indicative of cardiosclerosis were shown by 40 patients (46 %), inveterate infarct by ten (12 %), recent infarct by one (1 %), myocardial ischaemia by three (3 %) and a myocardiac defect by six (7 %).

Table 6. Distribution of 87 patients according to electrocardiographic findings.

ECG finding indicating	Cases	Per cent
Cardiosclerosis	40	46
Inveterate infarction	10	12
Recent infarction	1	1
Ischaemia of myocardium	3	3
Myocardial lesion	6	7
No change	27	31
Total	87	100

The ECG changes showed an increasing tendency with increasing age. ECG changes were seen in 78 % of the patients over 70 years (31 out of 40) and in 62 % of those younger than 70 (29 out of 47).

Infarctions were noted in seven men and four women (15 and 11 %, respectively); there is no statistically significant difference between sexes.

In 43 of the 87 patients subjected to ECG examination angina pectoris had been clinically established. 32 of them (74 %) showed ECG changes, while 11 (26 %) had a normal ECG. Of the 60 patients with ECG changes 36 (60 %) were such whose clinical examination had revealed angina pectoris.

Of the eleven infarctions determined from ECG, ten had also been established in the patient's previous history.

Comments

Changes in the ECG are rather common in patients with arteriosclerosis obliterans. For instance, Beckwith (1958) in iliac artery occlusion patients observed ECG changes in 63 %. The present series displays ECG changes in a somewhat higher proportion (69 %), but changes consistent with infarction are not quite as numerous: their rate of occurrence (13 %) is closer to the "post ischaemia" frequency (16 %) noted by Singer and Rob (1960) in patients with intermittent claudication. Infarctions were present, according to the ECG, in about one out of every eight patients (13 %), in close agreement with the number established anamnestically (12 %). About one quarter of the angina pectoris patients had a normal ECG, in agreement with Schettler's (1961) observations on such patients.

D Renal and renovascular hypertension

Previous investigations

According to various authorities (Howard and Conner 1964, Poutasse 1964) hypertonia is due in about 5—15 % to renal arterial stenosis. However, such stenosis does not invariably imply the presence of hypertonia. Holley et al. (1964) for instance noted in an unselected autopsy series of 256 patients without hypertonia more or less strong renal arterial stenoses in 49 %. It is possible, however, to distinguish the stenoses causing hypertension by means of Howard's test (Stamey 1963, Howard 1964) and Kaplan's hypertension test. Lemann (1964) states that he observed the following kinds of urinary changes in cases of

hypertonia due to constriction of the renal arteries merely minimal or moderate proteinuria variably red and white cells and cells of renal origin usually in increasing amounts and sometimes hyaline and granular cylinders The quantitative proteinuria is less than 0 5 g per day The changes were dependent on the degree of arteriolar nephrosclerosis

There is also a great number of other diseases causing hypertonia (Kinsey and Whitelaw 1964) of which glomerulonephritis and chronic pyelonephritis are the commonest Page et al (1959) maintain that it is not possible by means of examination of the bladder urine and function tests to distinguish bilateral from unilateral lesions nor arterial lesion from pyelonephritis

Concerning the commonness of hypertonia the fact may be mentioned that Boe et al (1957) found at mass examination in Norway the percentage of hypertonics (with 160 mm Hg or higher systolic blood pressure) to be 40 % of 60 year-old men and 50 % of women of the same age In Finland calculation from Tuomi s (1965) mass examination shows that hypertonics (with a blood pressure of 160/95 mm Hg or higher) among persons aged 60—65 years account for 16 % of the men 55 % of the women and 37 % of both together In arteriosclerotic patients with gangrene Heine et al (1965) obtained a value of 52 5 % for the percentage of hypertonics (with 155/100 mm Hg or higher blood pressure)

Present studies

The presence of proteins in the urine was investigated in 175 patients of the present series (Table 7) On the basis of the results the patients were divided into two main groups those with and those without proteinuria In the group of patients with proteinuria the boiling test elicited positive albumin reaction in 11 cases and opalization in 37 altogether 48 (28 % of those examined) were thus affected with proteinuria Ten of them had chronic pyelonephritis and all gave a positive albumin reaction No information exists on any other diseases of the urinary organs in them Among the patients whose albumin test produced an opal response cardiac insufficiency had been established in 15 In the proteinuria group 16 patients had a blood pressure of 160/100 mm Hg or higher In seven of them chronic pyelonephritis was responsible for their hypertonia In the remaining nine hypertonic (RR 160 mm Hg or higher) patients or in 15 % of all those with hypertonia, renovas

Table [illegible] Distribution of 48 proteinuric patients and of 1[illegible]5 patients without proteinuria according to rest nitrogen, s g of the urine and blood pressure (In brackets individual values found by the respective determination, rest nitrogen expressed in mg%)

Blood pressure mm Hg		Number of patients	Rest nitrogen		Specific gravity of urine		
Systolic	Diastolic		Normal	Elevated	Over 1015	1015–1014	Less than 1014
		Proteinuric patients					
< 160	< 100	1[illegible]	4	2 (49 6[illegible])	2	3	1 (*100[illegible]*)
≧ 160	< 100	13	6	2 ([illegible]4 54)	3	2	–
≧ 160	≧ 100	9	6	2 (90 60)	3	2	–
		Proteinuric patients with chronic pyelonephritis					
< 160	< 100	3	1	–	–	1	1 (*101[illegible]*)
≧ 160	< 100	–	–	–	–	–	–
≧ 160	> 100	7	4	–	2	[illegible]	–
	Total	48	21	6	10	10	
		Non proteinuric patients					
< 160	< 100	[illegible]4	19	[illegible]	–	6	
≧ 160	< 100	27	13	1 ([illegible]2)	2	3	
≧ 160	≧ 100	41	18	1 ([illegible]8)	4	11	[illegible]
	Total	1[illegible]5	[illegible]0	7	13	[illegible]0	

[illegible]) ([illegible]1 [illegible] 6[illegible] 7[illegible] *120*) [illegible]) Rest nitrogen normal

cular hypertension may have been present Their renal change[illegible] be very severe however seeing that only two out of eight cases [illegible] presented moderately elevated rest nitrogen (60 and 90 mg % re[illegible]tively) and one of these two had a 1 017 specific gravity of th[illegible] urin[illegible] The urine of four other patients was also examined for specific gr[illegible]vity which was higher than 1 025 in three cases and 1 022 in one the l[illegible]tter also having normal rest nitrogen

No grave renal lesions were elicited in the group of non proteinuric patients either only one of them had a specific gravity of the urine less than 1 014 and the amount of creatinine was found to be normal (0 84) even in this case Five of the normotonics had somewhat elevated rest

nitrogen but this was not accounted for by renovascular causes either, since the diastolic blood pressure of all these patients had remained normal

The series of 175 patients included 60 (35 %) hypertonics (with RR 160/100 mm Hg or higher) whose diastolic blood pressure was elevated too If increased systolic blood pressure alone (RR 160 mm Hg or higher) is considered the hypertonics number 95 (60 %)

Comments

In the series of patients with gangrene due to arteriosclerosis of Heine et al (1965) about one third were hypertonics (with 155/100 mm Hg or higher) Almost the same proportion of hypertonics (with 160/100 mm Hg or higher) was found in the present series consistent with the numbers usually encountered among persons of the same age

If the standpoint is assumed that proteinuria is associated with renovascular hypertonia due to arteriosclerosis then in about 15 % of the hypertonics of the present series there is a possibility of renovascular hypertonia Such a rate of occurrence is possible in the light of previous investigations since hypertonia is considered to be ascribable to stenoses of the renal arteries in about 5—15 %

VI EXTENT OF POST MORTEM ARTERIOSCLEROTIC CHANGES

A Autopsies

Previous investigations

On the strength of 200 autopsies Glagov and Rowley (1959) observed differences in the degree of severity of arteriosclerosis in different parts of the vascular system They found the following scheme for its distribution coronary arteries > thoracic aorta > abdominal aorta > renal arteries and they noted the relatively high degree in which the renal arteries were spared

The typical primary localizations of arteriosclerosis obliterans changes are the abdominal aorta the arteries of the pelvis and the femoral artery The changes increase in the aorta in the distal direction and are most powerful in the terminal aorta (Allen et al 1959 Roberts et al 1959) According to Ratschow (1959) 1 1 % of the circulatory disturbances are caused by obstruction of the artery

The degree of severity of the occlusions in the coronary arteries also reflects increased changes elsewhere in the vascular system for instance a distinct correlation exists between the changes found in the abdominal and coronary arteries (Roberts et al 1959)

Milles (1925) and Moschkowitz (1929) already observed changes in the pulmonary arteries in only 6—8 % of arterioslerotic patients Roberts et al (1959), too on the basis of 500 autopsies observed a noteworthy increase of arteriosclerosis in these arteries only in patients with cardiac infarction The changes in the intestinal arteries up to the age of 70 years were approximately consistent with those of the pulmonary arteries Holley et al (1964) established moderate and severe stenoses in patients over 50 years due to renal arteriosclerosis at an almost equal frequency in normotonics and hypertonics (64 and 76 % respectively)

As regards the region of the lower extremities Lindbom s (1950)

Table 8 Arteriosclerotic changes observed in a total of 39 autopsies in different parts of the arterial tree and their frequencies (in per cent in brackets) Only arteries mentioned in five or more autopsy reports have been listed

Part of the arterial tree	Number of examinations	Normal	Changes of degree			Thrombus present		Involvement as cause of death		Symptoms of occlusion prior to amputation
			Slight	Moderate	Severe	Obliterative	Adjacent to wall	Basic	Immediate	
Arteries of the base of the brain	29	6 (21)	6	7	10 (34)	1 (3)	–	3 (10)	5 (17)	5 (17)
Common carotid artery right	7	–	2	3	2 (29)	2 (29)	–	–	–	1 (14)
Common carotid artery left	6	–	2	3	1 (17)	1 (17)	1 (17)	–	–	–
Coronary arteries	30	1 (3)	4	8	17 (57)	7 (23)	–	10 (33)	3 (10)	7 (23)
Pulmonary artery	18	16 (89)	2	–	–	3 (17)	–	–	3 (17)	–
Mesenteric artery	[illegible]	–	1	2	2 (10)	2 (10)	–	–	–	2 (10)
Aortic arch	5	–	[illegible]	–	–	–	–	–	–	–
Thoracal aorta	21		11	4	6 (29)	–	1 (5)	–	–	–
Abdominal aorta	29	–	4	9	16 (55)	4 (14)	5 (17)	–	–	–
Common iliac artery right	9	–	2	2	5 (56)	5 (56)	–	–	–	–
Common iliac artery left	9	–	1	2	6 (67)	5 (56)	–	–	–	–
Superficial femoral artery right *)	6	–	1	1	4 (67)	2 (33)	–	–	–	–
Superfical femoral artery left*)	5	–	1	–	3 (60)	1 (0)	–	–	–	–

*) Upper parts

arteriographic and autopsy series showed changes in this region in the femoral artery in Hunter's canal to be commonest and severest. On the other hand the deep femoral artery was less affected by arteriosclerosis and rarely obliterated.

Sclerosis of the cerebral arteries is not distinctly correlated with changes in other arteries. Frovig and Loken (1951) for instance found the arteries of the brain to be well preserved even if the branches departing from the arch were completely obliterated. The cerebral arteries did not present any regularity in spread and degree of severity of arteriosclerosis either (Roberts et al. 1959).

The commonness of arterial occlusions in the region of the neck has not been noted until the last ten years. Fischer (1954) presented 432 consecutive autopsies in which 28 occlusions and 15 constrictions of the carotid arteries of a more serious degree were observed. Seven of the subjects presented unilateral occlusion without symptoms. Hutchinson and Yates (1957) described the autopsy findings on 83 patients who had clinical symptoms of cerebrovascular disease, finding that in 40 of them at least one half of the lumen of the carotid and/or vertebral arteries had been obliterated.

In persons over 50 years moderate and severe arteriosclerotic changes of the renal arteries are fairly common and stenosis of the renal arteries does not necessarily imply hypertonia (Schwartz and White 1964). In an unselected autopsy material of 154 patients older than 55 years Schwartz and White (1964) noted severe arteriosclerotic changes in about one half.

Present studies

As can be seen from Table 8, in which the results of 32 autopsies are presented, all parts of the arterial tree were not systematically examined. Only such arteries for which observations from at least five autopsies exist have been included in the table. The arteries of the base of the brain were examined in nearly all autopsied cases. Severe changes were present in one third (34 %) but only one case displayed an obliterative thrombus. The findings were normal in one fifth of the cases (21 %), and only the pulmonary arteries yielded a higher percentage of normal findings. Five of the 32 subjects had had apoplexy prior to amputation, but all five had made a good recovery. In five cases, too, the cause of death was cerebromalacia, but previous apoplexy had

occurred in only one of these In all five the vessels of the base of the brain were strongly calcified and one of them also had a thrombus of the middle cerebral artery, while one of the vertebral arteries was narrow in another and the common carotid arteries of a third subject were constricted The heart compression test had shown the internal carotid and vertebral arteries of these three patients to be open In the remaining two patients of this particular group the presence of extra cerebral occlusions was not ascertained

The internal carotid artery was not examined at all, and the vertebral artery was only partially investigated in one case Examination of the common carotid artery was made in seven instances, six of them bilaterally severe changes were noted in two (29 %) and a unilateral obliterative thrombus in three (43 %) Ischaemic symptoms had occurred in one of these prior to amputation but were not the cause of death in any of the cases

The most numerous examinations were those made of the coronary arteries i e, in 30 patients More than one half (57 %) presented severe changes while a normal finding was made only once (i e in 3 %) Cardiac infarction occurred in nine cases (30 %) of which five had an old infarction, two an old infarction and a recent one and two had a recent infarction only The cause of death was due to the coronary arteries in 10 cases (33 %), of which seven had had symptoms prior to amputation

The pulmonary arteries were normal in the majority (89 %) of the cases examined there were no severe changes at all Thrombus or embolism was noted in three cases (17 %) in which it had also been the cause of death

The mesenterial arteries were examined in five cases only they revealed severe changes in two cases accompanied by an obliterative thrombus Intestinal infarction due to thrombus was the intermediate phase (I b) between the fundamental and immediate causes of death in two cases Ischaemic symptoms of the intestinal circulation had been present in both prior to amputation

The severe changes observed in the aorta increased in the distal direction so that they occurred in the region of the abdominal aorta in more than one half of the cases (55 %) that is at nearly the same frequency as in the regions of the common iliac artery (55—67 %) and the superficial femoral artery (60—70 %) Only the proximal part of

the latter was examined. The highest number of thromboses was noted in the iliac arteries (57 %).

The kidneys were examined in 30 cases. Apart from the autopsy findings, the clinical results of observation concerning the kidneys and the interval between clinical examination and autopsy have also been entered in Table 9. Arteriosclerotic nephrosis of a severe degree was noted in seven of the autopsied cases (25 %), in two of which hypertonia had been present. The nephrosclerotic kidneys were found to have an average weight of 245 g.

A cicatricial kidney without specified cause occurred in six cases, in two of which renal infarction had been diagnosed. The kidneys in this group showed an average weight of 278 g.

Chronic pyelonephritis occurred in five cases (17 %) and diabetic nephropathy combined with pyelocystitis in one. These kidneys had an average weight of 304 g.

The remaining 12 cases revealed no changes of the kidneys worth mentioning; they also showed the highest average kidney weight, 330 g. The difference of 85 g in comparison to the group affected with nephrosclerosis is statistically almost significant ($P < 0.05$).

Altogether nine of the autopsied patients (31 %) had hypertonia, and two of these showed severe sclerosis of the renal arteries.

Comments

The same observation can be made in the present series as was noted by Roberts et al. (1959) in their autopsy series, that the pulmonary arteries escaped arteriosclerosis fairly well. They constitute the group showing the smallest number of arteriosclerotic changes, i.e. only slight changes in every ninth case. The arteries of the base of the brain were also free of atheroma to rather a great extent (occurrence in one out of every five cases). Commonest and roughly equal in frequency (in 1/2 to 2/3) were severe changes in the coronary arteries, abdominal aorta and arteries of the pelvis. The changes increased in the aorta in the distal direction, as was also observed by Allen et al. (1959) and Roberts et al. (1959) in patients suffering from arteriosclerosis obliterans. Obliterative thrombus was commonest (in about 1/) in the region of the common iliac artery. The same amount of fresh thrombi completely occluding

VII SYMPATHECTOMY AS AN AMPUTATION-PRECLUDING TREATMENT

Previous investigations

It has been said that sympathectomy is an operation producing vasodilation and hyperaemia (Block 1957 Fontaine 1959) and improving the collateral circulation (Edwards 1957 Mayer Burgdorff 1960 Ballinger 1965) The frequency of favourable results after sympathectomy performed in association with peripheral arterial occlusion diseases varies between 17 % and 88 % (Senn 1965)

Reported experiences (Nystrom 1949 Wanke 1953 Berry et al 1955 Block 1957 Fontaine 1959 Kunlin 1959 Holopainen 1963 Dale 1965 Szilagyi 1965) indicate that the results obtained by sympathectomy are least favourable in the rest pain and necrosis stages which are exceedingly difficult to influence In the opinion of Berry et al (1955) sympathectomy is contraindicated in gangrenous patients over 60 years if their popliteal artery pulsation is absent If cutaneous lesion is present when sympathectomy is made major amputation rather often ensues (Telford and Simmons 1946 in 49 % De Bakey et al 1950 in 65 % Berry et al 1955 in 41 % Pratt 1955 in 66 % Gillespie 1961 in 57 %)

Better results have been reported after sympathectomy at the intermittent claudication stage (Hamalainen 1943 Nystrom 1949 Lindstrom 1952 Bittner 1958 Kunlin 1959 Wanke 1959 Dale 1963 Holopainen 1963 Ballinger 1965) after which gangrene develops in less than one third (*Bittner and Stephan 1958 in 30 % Gillespie 1960 in 15 %* Mayer Burgdorff 1960 in 20—30 %)

The success of the operation is also affected by the height of occlusion The results are poorer when occlusion of the abdominal aorta or of its main arch is concerned (Silbert and Zazeela 1958 Fontaine 1959 Gillespie 1961) while good results have been obtained in peripheral occlusions in the region of the lower leg (Holopainen 1963 Ballinger 1965 Schoop 1965 Szilagyi 1965) Mavor (1956) thinks that the height

of occlusion has no effect on the result of sympathectomy. Koskinen (1965) has drawn attention to the favourable effect of sympathectomy in distal arterial lesions due to trauma.

Most important among concomitant diseases is diabetes, which impairs the results, e.g. according to Nelson and Trimble (1956), Silbert and Zazeela (1958) and Thimming et al. (1958), but Edwards (1957), Gillespie (1961) and King et al. (1964) maintain that sympathectomy is also suitable for diabetics. Furthermore, the general extent of arteriosclerosis exerts an influence on the outcome. In the case of previous cardiac infarction, cerebrovascular accident or visceral ischaemic symptoms, poorer results have been noted than in the absence of such manifestations (Ballinger 1965), *particularly if the patients are hypertonics or diabetics* over 65 years of age (Berry et al. 1955).

Pre-ent studies

The distribution of amputations among the 64 sympathectomized patients of the present series is given in Table 11. Of 93 extremities treated by sympathectomy, 78 were subsequently amputated and 15 extremities escaped amputation.

The mean age of the sympathectomized patients was 62.5 years and that of the patients whose one extremity was saved and of those who underwent amputation after sympathectomy was 61.9 and 62.6 years, respectively. The proportion of diabetics in these two groups was 13.3 and 20.4 %, respectively. No statistically significant differences exist

Table 11. Distribution of 64 patients' extremities according to unilateral or bilateral sympathectomy and amputation

	Number of patients	Number of sympathectomized extremities	Number of amputated extremities	Number of extremities saved
Unilateral amputations				
Unilateral sympathectomy	33	33	33	
Bilateral sympathectomy	15	30	15	15
Bilateral amputations				
Unilateral sympathectomy	2	2	2	
Bilateral sympathectomy	14	28	28	
Total	64	93	78	15

between the groups. The age at amputation of the non-sympathectomized patients was 71.7 years on the average; the difference of 9.4 years in comparison to the sympathectomized patients is statistically highly significant ($P < 0.001$).

Table 12. Clinical and operative-prognostic classification of 78 sympathectomized extremities

Classification	Amputated extremities		Extremities saved	
	Number	Average sympathectomy–amputation interval month	Number	Average time from sympathectomy to death years
Clinical classification (Leriche-Fontaine)				
Little or no symptoms	–		–	
Intermittent claudication	32	34	15	4.5
Rest pain	16	3.5	–	
Necrosis or gangrene	30	1.4	–	
Total	78	4.3	15	4.5
Operative-prognostic classification (Wanke)				
No necrosis	48	23	15	4.5
Necrosis or gangrene	30	1.4	–	
Total	78	4.3	15	4.5

Logarithmic mean

Sympathectomy was performed (Table 12) on the side of the amputated extremity at the intermittent claudication stage in 32 cases (41 %), at the rest pain stage in 16 (20 %) and at the gangrenous stage in 30 (39 %). The average time interval between sympathectomy and amputation was 2 years 10 months in the cases sympathectomized at the claudication stage, but only 3.5 and 1.4 months respectively in those subjected to sympathectomy at the rest pain and necrosis stage. On the side of the extremity left intact sympathectomy had invariably taken place at the intermittent claudication stage and the time the extremity remained intact (up to death) averaged 4.5 years.

In those [illegible] claudica[illegible] and in those [illegible] years. The time [illegible] pathectom[illegible] respectively. [illegible]

Table 15 shows [illegible] types [illegible] pathectomy and [illegible] sympathectomy and amputation [illegible] occlusion [illegible] was involved the difference [illegible] and that involving the [illegible] $(P < 0.01)$ and that between the [illegible] statistically almost significant $(P <$ [illegible]

Table 15. Types of occlusion at the time of [illegible] tomy to amputation in series [illegible] patients.

Type of occlusion	Number of patients	[illegible]
Pelvic region	11	[illegible]
Femoral region	29	[illegible]
Peripheral	23	
All pulses feeble	[illegible]	
Not recorded	[illegible]	
All cases	[illegible]	[illegible]

* Logarithmic means

Expedients of vascular surgery other than sympathectomy were applied in attempts to improve the circulation of extremities in four cases with rather satisfactory results. In the case of three patients arterial reconstruction was performed and in another thromboendarterectomy in the thigh. One gangrenous extremity thus escaped amputation; in the other three amputation did not follow until after 1.5—5 years.

Comments

The mean age of the sympathectomized patients in the present series was found to be 9 4 years lower than that of the complementary group, which amounts to a statistically highly significant difference However, this can hardly be claimed to be a consequence of sympathectomy, since the disease had already reached the rest pain and necrosis stage in about one half of the patients prior to sympathectomy, and no paradoxical reactions were noted after sympathectomy It seems that in the group of sympathectomized patients the disease progressed rapidly and extensively more often than average so that the results of sympathectomy were poorer (cf De Bakey 1958, Senn 1965), as were also those of sympathectomy in the gangrenous stage Here, as in general the best results were elicited by sympathectomy performed at the intermittent claudication stage in one out of every three such cases amputation was avoided and in the rest, too on the average nearly three years passed before amputation ensued, whereas amputation followed as soon as 1 4—3 5 months after sympathectomy at the rest pain and gangrenous stage The height of occlusion too affects the results (Silbert and Zazeela 1958 Gillespie 1961) Here, too, better results are noted when the occlusions were peripheral In such cases the interval between sympathectomy and amputation was on an average three times that observed in connection with occlusions in the pelvic region The extremities that remained intact presented peripheral occlusions at a frequency twice as great as that for the amputated extremities and there were no occlusions at pelvic height which occurred at the time of sympathectomy in about one of every five patients subjected to amputation (Table 4 p 46)

VIII HEIGHT OF AMPUTATION AND HEALING OF THE STUMP

Previous investigations

In series of amputations in which arteriosclerosis was the sole or principal reason for amputation amputation at the thigh has been commoner than amputation at the lower leg (Table 14) but in a few series compiled in recent years the latter begins to be almost as frequent or even more common than amputation at the thigh (Allfram and Holmquist 1961 Erikkis and Brownell 1963 Hallen and Hult 1964) However in 1961 in the 13 biggest Swedish hospitals lower leg stumps accounted for 32 % of the thigh and lower leg amputees (Hallen and Hult 1964) Prior to the introduction of antibiotics most amputations had to be performed at the thigh owing to the common imminence of sepsis and wound infection after amputation at the lower leg For instance Perlow (1962) observed that in his series of amputations those at lower leg height had increased from 6 % of all amputees in 1936—1938 to 32 % in 1945—1956 At the same time the mortality went down from 29 % to 14 4 %

Digital and metatarsal amputations are less frequently successful in arteriosclerotics than in diabetics (McKittrick et al 1949 Regan et al 1949 Warren et al 1952 Wheelock 1961) and they are often intermediate to final upper or lower leg stumps

The optimum height at lower leg amputation is according to Perlow (1962) from the middle third to 8 cm below the tuberosity of the tibia but 2—3 cm below the latter is sufficient for a lower leg prosthesis According to Mercer and Duthie (1963) a serviceable prosthesis can be fitted to a 2 inch stump and in Thompson s (1963) opinion a 3 inch stump is adequate for a total contact patellar bearing prosthesis

If no possibility exists for lower leg amputation then exarticulation of the knee is recommended by McKenzie (1953) and by Hopkins and Harris (1965) while Record (1963) and Thompson (1963) advocate amputation at the thigh

Table 11 Healing of lower and upper leg stumps in some previous series and in the present series

Reference	Number of amputations	Amputations at (1) Lower leg	Amputations at (2) Upper leg	Reamputations After (1)	Reamputations After (2)	Secondary healing Lower leg	Secondary healing Upper leg	Cause of amputation
Silbert and Haimovici (1950)	213	213		10 (5 %)				3/4 of series diabetics
Kelly and Janes (1957)	245	131	114	9 (9 %)				
Glaugus et al (1958)	118	47	71	6 (13 %)	1 (1 %)	(76 %)*	(21 %)*	Arteriosclerosis
Dale and Capps (1959)	284	65	219			33 (51 %)	75 (34 %)	259 arteriosclerotics
Schlitt and Serlin (1960)	96	28	68	7 (25 %)	0	9 (32 %)	10 (15 %)	87 arteriosclerotics
Harris et al (1961)	52	52		10 (19 %)		(21 %)*		
Dale and Jacobs (1962)	About 270*)	45*)	225*)			(39 %)	(2, %)	Arteriosclerosis
Lempke et al (1963)	200	**)	**)			(98 %)	(4 %)	Arteriosclerosis
Present series	219	24	195	9 (37 %)	9 (5 %)	5 (21 %)	26 (13 %)	Arteriosclerosis

*) Calculated from data presented **) Amputations both at lower leg and at thigh numbers not stated

As contraindications of lower leg amputation Claugus (1958) enumerates the following: abrupt change in temperature above the planned incision, failure of capillary [illegible], scanty haemorrhage during operation, particularly from subcutaneous tissue, absent pulsation of the femoral artery. These are generally acknowledged (Silbert and Haimovici 1950, Kendrick and Jones 1957, Thompson 1965). Concerning the pulses, however, opinions differ. Silbert and Haimovici (1951) and Thompson (1965) consider that if there is extensive gangrene, infection in the lower leg and absence of the femoral artery pulse or acute occlusion of the femoral artery, lower leg amputation will not be successful. In the absence of pulsation in the popliteal artery lower leg amputation will be successful (Perlow 1962, Eraklis and Brownell 1965) but according to Harris et al. (1961) the chances of success are smaller than if the pulse of the popliteal artery is palpable.

The basic cause of wound complications may be considered to be poor vascularization of the tissues and infection in the lymph passages of most patients (Dale and Capps 1959) but surgical assessment of the tissues and amputation technique also play an essential role (McKittrick and Pratt 1954, Perlow et al. 1949, Silbert and Haimovici 1951, Kendrick 1956, Claugus et al. 1958, Dale et al. 1959, 1962, Perry 1965) so that most wound complications can be avoided by using the correct amputation technique and antibiotics (Dale and Capps 1959).

Various opinions have been expressed concerning the effect of sympathectomy on the height of amputation. It has been said that a longer stump is obtained on a sympathectomized extremity (Perlow and Roth 1949, Pratt 1955, Flotte 1959) or that the expedient does not affect the height (Kirschner 1951, Lempke et al. 1965). Gibbel (1960) and Gillespie (1961), among others, think that sympathectomy has a favourable influence on the healing of the stump.

Present studies

a) The effect of sympathectomy on the healing of the stump

Table 15 shows a comparison between the healing of the amputation stump in extremities subjected to sympathectomy and those on which this was not performed. Objects of comparison are the occurrence of reamputations and wound complications of considerable severity (cases in which the stump did not heal in four weeks) and the distribution of stumps in both groups.

Comments

It can be seen from Table 14 that in the patients subjected to amputation on account of gangrene caused by arteriosclerosis wound complications of the stump are fairly common Secondary healing of extremities amputated at the lower leg took place in 25—51 %, and the reamputation frequency was up to 25 % Upper leg stumps display wound complications less often than lower leg stumps and reamputations at the thigh are rarely necessary

In the present series amputation at the lower leg was performed in only about one out of every nine cases and reamputation was needed in somewhat more than one third of them While there were more wound complications and reamputations after amputation at the lower leg than usual the wound complications after amputation at the thigh were less numerous than average but reamputations were rather numerous in this group too

Dale and Capps Jr (1959) observed that profuse wound complications are due to inappropriate amputation techniques and incorrect surgical assessment of the tissues In the present series too wrong surgical assessment of the tissues constituted the principal cause of wound complications and a nearly equal share is attributable to faulty amputation techniques the former finds an obvious explanation in attempts to obtain stumps of optimum dimension nearly all lower leg stumps were 15 cm in length or longer Infections contributed less to reamputation than they did to other wound complications

The effect of the height of occlusion was clearly established in respect of the upper leg stumps which healed better when a peripheral occlusion was concerned than in the case of occlusion in the pelvic region Amputation at the lower leg was not more often successful in those whose popliteal artery pulse was palpable than in those failing to present this pulsation Sympathectomy was not found to have any influence on the healing of the stump

IX RECOVERY, LIFE SPAN, ABILITY TO MOVE, AND CAUSES OF DEATH

Previous investigations

Factors affecting the recovery and life span after amputation are e g age at amputation height of amputation sex concurrent diseases such as diabetes and coronary arteriosclerosis and preoperative and post operative treatment (Veal 1938 McKenzie 1953 Dale and Capps 1959 Lempke et al 1963) The data compiled in Table 18 show that the average life span after amputation varied between 1 year 8 months and 2 ¾ years

In addition to the data concerning life span information on amputation mortality and causes of death has been compiled in Table 18 from some previously published series Before the era of antibiotics the operation mortality varied between 13 and 60 % in a composite material of 2 682 cases for instance it was 27 % (Silbert and Haimovici 1950)

The mortality of patients amputated at the lower leg varies in the series covered by Table 18 from 0 (Claugus et al 1958) to 9 % (Silbert and Haimovici 1950) and that recorded at amputation at the thigh from 6 1 % (Claugus et al 1958) to 60 % (Morrisania 1942 rev by Silbert and Haimovici 1950)

In rehabilitation arteriosclerosis is the most essential factor restricting the use of a prosthesis (Bugel and Carlson 1961) After amputation only about one half of the older gangrenous patients become prosthesis walkers (McKenzie 1953 49 7 % Alffram and Holmquist 1961 50 % Claugus et al 1958 49 %) The percentage of amputees walking at the time of follow up examination is reported as 28 % by Lindholm (1964a) as 44 % by Gingres et al (1954) and as 31 % by Hansson (1964)

Lower leg stumps present several advantages over upper leg stumps lower operative mortality better ultimate function of the extremity and better chances of rehabilitation less strain on the contralateral extremity better equilibrium without prosthesis in moving about on crutches in a wheel chair and in bed lighter weight of the prosthesis for which

an older person's strength is more adequate easier sitting and moving in bed for bilateral amputees (Abramson 1942 Silbert and Haimovici 1950, Claugus et al 1958 Harris et al 1961, Perlow 1962, Perry 1965, Record 1965)

In Hansson's (1964) series of unilateral amputees older than 60 years 72 % required constant home or institutional care The proportion of such patients in Lindholm's (1964a) series was 91 9 %

Since arteriosclerosis is present in a considerable portion of the amputees it is not surprising that cardiovascular diseases constitute the principal cause of death. For instance Lindholm (1964a) noted that of 86 patients subjected to amputation at an age of over 65 years 40 died within 2 1/4 years of the amputation and that in 77 5 % of these the basic cause of death was arteriosclerosis In Hansson's (1964) series the postoperative deaths during the first year amounted to 41 % and of those over 60 years 90 % died of a cardiovascular disease

Present studies

a) Recovery and life span after amputation

Those who died within 14 days of the amputation were considered to represent the operative mortality they numbered 38 (21 %) Another 15 patients died in the hospital after this period and the hospital mortality thus took a toll of 53 patients (29 %) Of those who were discharged 74 had died at the time of writing this report (40 %) The mean life span after amputation of all patients who have died up to now is 1 8 years For bilateral amputees the life span was counted from the later amputation

The patients living at the time of follow up examination numbered 57 (31 %) The shortest and longest life spans after amputation of the patients subjected to follow up examination were 1 year 1 month and 13 years 10 months respectively the average life span being four years

The life spans after amputation of all patients in the present series have been analyzed and the results presented in Fig 10 curve A The cumulative distribution curves were plotted for different ten year age groups including both those who died before follow up and those still alive Entering these graphs at 50 % decession the mean post amputation life spans for these groups were found and entered in Fig 10 and thus represent the times after which one-half of the patients in each such group had died The curve B has been drawn for purposes of comparison

Table 18. Postoperative mortality, life span after amputation and causes of death in some series [illegible]

Reference	Period covered	Number¹)	Cause	Height²)	Primary mortality: Deaths	Primary mortality: Per cent	Life span after amputation	Cause of death
McKittrick and Pratt (1934)	1923–33	3 6 A	Diabetes	L & T	19	1	About 2/3 survived [illegible]	Infection in [illegible] 1/?
Taxon (1939)	1929–39	262 A	Peripheral vascular disease	Major amputation		13 1	61 % of the arteriosclerotics died within 5 years	
Taylor (1939)	1930–38	117 P, 137 A	Arteriosclerosis	Major amputation	44	3?³)		
Morrimann (rev. by Silbert and Haimovici 1950)	1931–3	4?1	Diabetes	T	27	60		
Lindholm (1961b)	1930–61	49? P	Peripheral vascular disease	Digit, L & T		6 6		Operative deaths from cardiovascular disease, infection and other causes in 43, 3? and 25 % respectively
Ho (1961)	1936–44	11 A	Arterial occlusion disease	L & T	4	21		
	1945–58	157 A	Arterial occlusion disease	L & T	22	11 4		
Silbert and Haimovici (1950)	1910–49	213 A, 196 P	Diabetes	L	20	9 4		
Hansson (1964)	1947–56 & 1961	331 P	Arteriosclerosis in majority (?30)	L & T	9	18	19 months those over 60 years, ?0 months in entire series. Deaths within 0.5, 1, ? and 5 years 36, 41, 58, 8 % resp. Within 1 and 2 years 1? and 5? respectively	
Chilg? et al (1958)	194?	118 A	Arteriosclerosis	T – 71, L – 47	?, –	12, 0		
Dale and Capps (1959)	1948–58	81 A, 37 P	Arteriosclerosis in ?9	T – ?19, L 65	14, 3	0, 16 } 0		
Harris et al (1961)	1948–?8	5 P	Peripheral vascular disease	L	3	6		
Alffram and Hulmquist (1961)	1949–58	119 P	Peripheral vascular disease 10? arteriosclerotic	L & T	0	13 4	Average ?7 months. 31 5 % died within 1/2 year. 10 % of those over 60 died within one year	Operative deaths: cardiac infarction 9 (18 %), cardiac insufficiency in 6 (1? %). Pulmonary infarction in 18 (37 %), pneumonia 3 (6 %); cardiovascular disease in 77 %
Schlitt and S?rlin	1953–?8	?6 P, 1?9 A	Peripheral vascular disease	L – ?8, T – 68	?, 9	7, 13 } 1		
Dale and Jacobs (196?)	1956–60	337 P	Mostly peripheral vascular disease	L, T	36			Cardiac infarction or failure in 10 (27 ?%)
Lindholm (1964a)	1961–63	86 P	Over 65 years	T, L – 16		19	41 ?% died within ? years. Mean age of deceased 78 6, of entire series ?6 years	Pulmonary embolism in 9 (? %). Cerebrovascular accident in 5 (14 %). Cardiovascular complication or pulmonary embolism in 83
Present series	1950–63	184 P, 19? A	Arteriosclerosis	L ?, T 195	–, 53	0, 27 } ?4	Deaths within 0.5, 1 and ? year 3?, 41, 18 % respectively. Total deaths ?8	Cardiovascular disease in 80 at least

1) A – Number of amputations, P – Number of patients. 2) L – Lower leg, T – Thigh. 3) Calculated from data presented.

and indicates the mean life expectation of corresponding age groups in an unselected population The values for this graph were calculated from data referring to the periods of 1951—1955 and 1956—1960 taken from the Finnish Statistical Yearbook in the calculations the specific sex distribution of each ten year age group of the present series was taken into account

In the group of patients subjected to amputation at an age below 50 years no deaths occurred All these three patients are alive the time since amputation varying from 6 to 14 years In the group of patients aged 50—59 years at the time of amputation, 13 had died and 14 were alive at the time of the follow up study, with time intervals after the amputation ranging from 1 to 11 years On the strength of the cumulative distribution graph, the mean life span after amputation was 3 years in this group In the 60—69 age group, 45 patients had died and 20 were still alive the latter after periods between 1 and 8 5 years, counted from the amputation As before a mean life span of 2 years 2 months

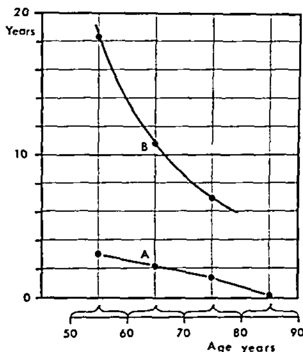


Fig 10 Graph (A) showing the survival time after amputation of 50 % of the patients in different ten year age groups (age at time of amputation deaths prior to follow up study and survivors at follow up both taken into account) For comparison graph (B) indicates the mean (50 %) life expectancies calculated from data obtained from the Statistical Yearbook of Finland for unselected populations in the same age brackets and having male female composition equivalent to those in the present series

was found for this group The corresponding figures for the 70—79 age group are 49 deaths and 16 survivors with post amputation periods ranging from 1 to 10 years and mean life span 1 year 4 months Of those amputated at an age of 80—89 years 19 had died and three were alive three years having passed since the amputation in all three cases For the amputees of this group the cumulative distribution analysis gives a mean life span of only about one month The longest postoperative survival time noted among those who were still alive at the time of follow up examination was not exceeded by the final life span of any individual in the respective age group except for one case in the 80—89 year group in which the patient had lived for 4 5 years after the amputation

It is evident from Fig 10 that the life expectation of those subjected to amputation at ages between 50 and 60 years was shortened by about 15 years and that of the patients whose amputation occurred at an age between 60 and 69 years by nine years In the age group of 70—79 years and presumably also in that of 80—89 years the shortening of life expectation seems to be 5—6 years when compared with an equivalent unselected population

In Table 19 a comparison has been made between those who died in the hospital those who died later and the patients who survived the amputation by more than three years and an additional group of all cases with fatal termination during the period of observation Both sexes are about equally represented in all groups except that men are relatively more numerous among those whose survival time was longer than three years though not at a statistically significant level But on comparison of these survivors with the groups of patients who died in the hospital and those who died later statistically highly significant differences ($P < 0\,001$) are noted in their mean age at amputation in every instance Those who died in the hospital were older, on an average by 2 1 years than those who died later and 7 9 years older than the three year survivors Patients older than 70 years at the time of amputation account for about 1/4 (24 %) of those who survived more than three years and for about one half (50—57 %) of the other groups, which amounts to a statistically highly significant difference ($P < 0\,001$) No statistically significant differences were elicited from the number of instances in which haemoglobin values over or under 12 g per 100 ml occurred in the different groups In the entire series 59 % of the patients had haemoglobin values lower than 12 g indicating anaemia The frequency of diabetes was fairly equal in all groups but angina pectoris occurred only

half as often in the three year survivor group as in the other groups the differences being statistically highly significant ($P < 0.001$) No statistically significant differences are noted in other symptoms of occlusion in hypertonia or in the distribution of different types of occlusion between the groups

All the patients who died in the hospital had had their extremity amputated at the thigh The percentage of lower leg amputees is accordingly higher among those who died later and among the three year survivors than among the hospital deaths The group of three year survivors also contains a greater number of bilateral amputees than the group of those who died earlier All these differences are statistically almost significant ($P < 0.05$)

Among those who died in hospital a good general condition was recorded in two cases (4 %) only while a corresponding assessment has been made in nearly one third (30—32 %) of those who died later or who survived longer than three years the differences being statistically almost significant ($P < 0.05$) A poor general condition was noted in about two thirds (62 %) of those who died in the hospital but only in about every eighth (12 %) of the three year survivors The differences between this group and the group of later deaths as well as that between the three year survivors and all deaths combined are statistically highly significant ($P < 0.001$)

In 179 of the 219 amputees amputation at the lower leg or thigh was the sole operation whereas digital amputation sympathectomy or other operations immediately preceded the leg amputation in the rest The preoperative treatment in these 179 cases had an average duration of 4 4 days 48 % of them were operated within 1—3 days after admission to the hospital 80 % within 1—6 days and all 179 within 12 days

b) Rehabilitation of the follow up patients

At the time of the follow up study 57 patients of the series were alive and 38 of them (67 %) were subjected to follow up examination The examination revealed (Table 20) that 18 patients (47 %) walked with a prosthesis and six (16 %) on crutches six examinees (16 %) were wheel chair patients and eight (21 %) were confined to bed These latter were on an average 10 9 years older than the prosthesis users the difference being statistically almost significant ($P < 0.05$)

The patients able to walk included 12 % bilateral amputees and 58 % wheel chair and bed patients combined with a statistically almost

Table 19 Comparison of the groups of patients who died in hospital later and altogether and of those who survived three years after amputation

	Patients lost						Patients surviving three years	
	in hospital		later		altogether			
	53 cases		*74 cases*		*127 cases*		*50 cases*	
	Number	%	Number	%	Number	%	Number	%
Men	28	*53*	42	*57*	70	*55*	35	*70*
Women	25	*47*	32	*43*	57	*45*	15	*30*
Mean age years	71.4		69.3		70.3		63.5	
Patients over 70 years	30	*57*	37	*50*	67	*53*	12	*24*
Hb over 12 g per 100 ml	21	*40*	18	*24*	39	*31*	17	*34*
Hb less than 12 g per 100 ml	25	*47*	42	*57*	67	*53*	32	*64*
Blood pressure over 160/100 mm Hg	32	*60*	50	*67*	82	*65*	26	*52*
Diabetes	13	*26*	21	*28*	34	*27*	11	*22*
Angina pectoris	15	*28*	21	*28*	36	*28*	7	*14*
Apoplexy	12	*23*	13	*17*	25	*20*	7	*14*
Intermittent claudication	28	*53*	47	*63*	75	*59*	32	*64*
More than one symptom of occlusion	16	*30*	22	*30*	36	*28*	13	*26*
No symptoms of occlusion	12	*23*	17	*23*	29	*23*	18	*36*
Occlusion in pelvic region	23	*43*	22	*30*	45	*35*	17	*34*
Occlusion in femoral region	15	*28*	26	*35*	41	*32*	16	*32*
Peripheral occlusion	13	*25*	22	*30*	35	*28*	14	*28*
Amputation at thigh	53	*100*	74	*100*	121	*100*	46	*92*
Amputation at lower leg	–		6	*8*	6	*9*	4	*8*
Bilateral amputation	8	*15*	14	*19*	22	*17*	14	*28*
General condition at amputation – good	2	*4*	22	*30*	24	*19*	16	*32*
– fair	15	*28*	30	*40*	45	*35*	25	*50*
– poor	33	*62*	20	*27*	53	*42*	6	*12*

significant difference ($P < 0.05$) Of the bilaterally amputated prosthesis users two had pylons in their upper leg stumps and the third had lower leg and upper leg stump prostheses Pylons had also been made for the two bilaterally amputated wheel chair patients but had been used a few times only

Only two of the prosthesis walkers (11 %) had visited the rehabilitation department for walking exercise and rehabilitation, while the others had taught themselves to walk at home after receiving some instructions at the prosthesis workshop. Attempts had been made among the unilateral upper leg amputees who were under institutional care, to make two wheel chair patients and two bed patients walk on crutches but without success. One of the crutch walkers had been hospitalized in a rehabilitation institution for two weeks after apoplexy and had then learned to walk on crutches. In connection with the follow up examination, prostheses were recommended to four of those walking on crutches. No essential difference was noted in the occurrence of diabetics among the walking and non walking examinees but cardiac insufficiency and cerebral circulatory disturbances were more common among the latter.

Table 20. Comparison of 38 patients subjected to follow up examination classified according to their ability to move

	Prosthesis walkers *18 cases*	Walking with crutches *6 cases*	Wheel chair patients *6 cases*	Bedfast patients *8 cases*
Men	12 (67 %)	5 (83 %)	4 (67 %)	5 (62 %)
Women	6 (33 %)	1 (17 %)	2 (33 %)	3 (38 %)
Mean age years	61.9	70.3	71.0	75.8
Unilateral amputations at lower leg	6 (33 %)	2 (33 %)	–	–
Unilateral amputations at thigh	9 (50 %)	4 (67 %)	3 (50 %)	3 (37 %)
Bilateral amputation	3 (17 %)	–	3 (50 %)	5 (62 %)
Walking exercises held	2 (11 %)	2 (33 %)	2 (33 %)	2 (25 %)
Diabetes	5 (28 %)	–	1 (17 %)	2 (25 %)
Angina pectoris	5 (28 %)	2 (33 %)	2 (33 %)	3 (37 %)
Cardiac insufficiency	3 (17 %)	1 (17 %)	2 (33 %)	5 (68 %)
Disturbance of cerebral circulation	–	–	1 (17 %)	2 (25 %)
At work	3 (17 %)	–	–	–
Living at home	7 (39 %)	4 (67 %)	3 (50 %)	–
Living in home for aged	10 (56 %)	–	2 (33 %)	3 (37 %)
Living in nursing home	1 (6 %)	2 (33 %)	1 (17 %)	5 (63 %)

Three of the prosthesis walkers (17 %) went to work All these were younger than 55 years at the time of examination a machinist aged 52 2 years with one extremity amputated at the thigh and the other at *the lower leg an insurance salesman aged 55 8 years, and a typesetter* aged 54 who had had both extremities amputated at the thigh and who could take the lift to his place of work in the house where he lived Of the follow up examinees 14 (37 %) lived at home and 24 (63 %) in institutions

c) Causes of death

The observation has already been made that the contribution of arterio sclerosis to the basic causes of death was 71 % This percentage is somewhat lower (66 %) when taken from autopsies than when taken from death certificates written without autopsy (73 %)

Causes of death other than arteriosclerosis were found in 54 cases (29 %) under 33 different headings, which have been combined to form seven larger groups (Table 10 p 64) The deaths are fairly equally distributed among these groups The highest percentage (7 %) is that of diseases of the heart other than coronary sclerosis (mostly cardiac insuf ficiency) However in about one out of every five autopsied cases diabetes has been considered the basic cause of death

As immediate causes of death cardiac diseases (23 %) and pneumonias (14 %) are commonest Cardiovascular diseases account for 80 % of the basic and for 72 % of the immediate causes of death based on autop sies however the percentages are lower (66 and 50 % respectively)

Comments

Consideration of the patients recovery after amputation reveals that about one out of every five patients died within 14 days of the operation Still further deaths occurred in the hospital at a later time and the hospital or primary mortality in the series thus amounts to about one quarter of all amputees Series reported by previous investigators (Table 18) show lower amputation mortalities However six months after the amputation the series of Alffram and Holmquist (1961) and Hansson (1964) and the present series already display the same percentage of deaths (31 5—36 %) One of the causes responsible for the comparatively high operative mortality in the present series can be considered to be the fact that most amputations were made at the thigh which implies a

higher fatal risk than amputation at the lower leg None of the lower leg amputees died in this series The patients age and their preoperative and postoperative treatment also affect the operative mortality Those who died immediately after operation in the present series had a higher mean age than those who succumbed later The preoperative treatment had only a mean duration of 4 4 days whereas Record (1965) for example recommends 2—3 weeks of such treatment prior to amputation

The average life span after amputation was 3 years for patients aged 50—59 years and only one month for those between 80 and 89 years Compared to unselected populations of equivalent age, the life span of the former had been shortened by about 15 years on the average and that of the latter by 4—5 years Thus no long life expectations can be given after amputation All possible expedients of vascular surgery and conservative treatment should therefore be applied at the gangrenous stage at the latest in order to save the extremity so that the patient may have the chance of continuing a fairly normal life in his home surroundings It should be noted that according to the follow up study of the amputees only one third of them were able to manage at home while two thirds were in institutions Amputation also causes considerable restrictions of movement only one half of the patients could move with a prosthesis, as has been noted in general concerning such patients too The decisive influence of age in the successful use of a prosthesis has been stressed e g by Schlitt and Serlin (1961) Wolters (1961) and Lindholm (1964a) In the present series those walking with a prosthesis show a mean age of 65 years which is nearly 11 years less than the mean age of the patients who were unable to move and confined to bed It cannot be said on the basis of the present study to what extent the ability to walk may be influenced by exercise In addition to age an important part is played by the height of amputation and by unilateral vs bilateral amputation

As regards the causes of death the observation can be made that 80 % of the patients lost during the period of observation died of cardio vascular diseases and more than two thirds of a disease due to arterio sclerosis This is rather common in series of this kind in the series of Lindholm (1964a) for instance universal arteriosclerosis was the cause of death in about three quarters (77 5 %) According to autopsies about one third of the deaths in the present series were due to coronary diseases and nearly the same proportion has been reported by Dale and Jacobs (1962) The mortality of pulmonary embolism in the present series (3 %) was perhaps lower than usual

X DISCUSSION

In persons older than 50 years gangrene of the extremities is a common manifestation of arteriosclerosis However the basic disease of *those subjected to amputation on account of arteriosclerotic gangrene* its gradual development and the extent of arteriosclerotic changes present in the different parts of the arterial tree have received little attention As a consequence fully relevant observations could not always be found in previous amputation *series for comparison with the results obtained* in the present study In such cases series of patients with arteriosclerosis obliterans or gangrenous patients were used for purposes of comparison some of whom were amputees or underwent amputation later in most instances

Arteriosclerosis usually begins to develop earlier and at greater strength in men than in women This fact is also evident in the present series of 184 patients subjected to lower extremity amputation on account of arteriosclerosis male patients dominated in a ratio of 3 2, the mean age of the men at amputation was 6 2 years lower than that of the women and bilateral amputations were about twice as frequent in men as in women

As a rule symptoms of occlusion produced by the effects of thrombosis begin to appear in patients with arteriosclerosis only from the age of 50 years onwards (Allen et al 1962 Sandler and Bourner 1963) In the present series too only three patients (2 %) were amputated at an age under 50 years the mean age of the amputees was nearly 70

No arteriosclerosis increasing effect of hypertonia (RR systolic 160 *mm* Hg or over) and diabetes was displayed in the present series As regards diabetes this is probably attributable to the fact that the disease was rather short in duration and of a slight degree as would be consistent with the clarification of the causality presented e g by Root (1950)

Consideration of the frequency of symptoms of obliteration in various parts of the arterial tree and the extent of arteriosclerotic changes in the corresponding areas reveals that the commonest symptom of occlusion

(60 %) was *intermittent claudication*, which was usually the first symptom to become manifest (on an average 2 7 years before amputation) and which became bilateral in most (80 %) of those affected with the symptom The duration of intermittent claudication and the proportion of bilateral symptoms are consistent with previous observations on intermittent claudication and gangrenous patients but the incidence is fairly low owing to the comparatively high proportion of older patients and diabetics

The arteriosclerotic changes were rather strong in the region of the lower extremities and pelvis as evidenced by arteriographies and autopsy findings According to the arteriographies the changes on the side of the extremity that remained intact were equal in order of magnitude to those observed by Singer (1965) in arteriosclerotic patients with ischaemia of the lower extremities but the number of multiple occlusions or occlusions obliterating the entire lumen of the vessel was 2—4 times as great on the amputated side Changes consistent with the arteriographs were found at autopsy Severe changes in the region of the abdominal aorta occurred in more than one half and in the common iliac and superficial femoral arteries in about two thirds of those examined About one half of the iliac artery occlusions were associated with thrombus The most notable difference as regards pulsation in the lower extremity arteries was that both pedal pulses were palpable in only three cases (2 %) on the amputated side but in 52 (17 %) on the other side

Next in commonness to the intermittent claudication symptom were (in about one quarter) symptoms from the coronary arteries infarctions beginning to be manifest on the average one year before amputation According to case histories and electrocardiograms cardiac infarction was present in about every eighth to tenth patient in conformity with the frequency observed by Heine (1965) in gangrenous patients According to the autopsies the number of infarctions was even higher amounting to nearly one in every three patients (30 %)

Symptoms of occlusion of the arteries branching from the arch of the aorta were somewhat less frequent than those of the coronary arteries that is about once in every five cases (22 %) They were mostly (in 19 %) cerebral ischaemic states which had resulted in apoplexy while only a few patients (3 %) had upper extremity symptoms Changes of the upper extremity pulsations were likewise rare (2 %) These findings are consistent with the frequencies noted in amputation and arterial occlusion patients (Ratschow 1959 Hansson 1964) The autopsies revealed severe

changes in the common carotid artery and in the arteries in the base of the brain in about one out of every three cases (34 and 29 % respectively)

Special examinations, which were not made in the present series would be required to reveal occlusions of the renal arteries (renal arteriography Howard s test angiotensin infusion test) However it can be said on the strength of normal routine examinations, that about every seventh proteinuric patient (15 %) had hypertonia (RR 160/100 mm Hg or higher) Similarly in every fifth autopsied case (22 %) arteriosclerotic nephrosclerosis and associated hypertonia was present and in these patients the possibility of renovascular hypertonia has thus to be taken into account which occurs in about 5—15 % of hypertonics (Poutasse 1959 Howard and Conner 1964) But the changes cannot have been very severe since there were no remarkable disturbances of renal function in any instance Such relative sparing of the kidneys has been noted e g by Glagov and Rowley (1959) This is confirmed by the fact that no disease of renal origin occurred as a basic or immediate cause of death in any case in the present series

In the intestinal region only two patients displayed distinct symptoms of obliteration in addition to which there were ischaemic symptoms suggestive of chronic circulatory derangement of the intestines in five The angina abdominis symptom occurred in one out of every 25 patients

Prior to gangrene and to the amputation stage in about one quarter of the present patients no symptoms of arterial occlusion had been noted However absence of symptoms of obliteration does not imply absence of arteriosclerotic changes and obstruction Thus for instance the pulmonary arteries alone were found to be normal in nearly all autopsies and the arteries of the base of the brain in about one fifth of them while there was hardly any instance in which the major arteries elsewhere had escaped arteriosclerosis

Sympathectomy was applied as treatment intended to obviate amputation in about one third of the cases In more than one half of these (59 %) it was performed at the gangrene or rest pain phase Sympathectomy was undertaken in an attempt to restore the blood circulation of the limb but amputation followed rather soon (within 1 4 to 3 5 months) The results were better after sympathectomy performed at the intermittent claudication phase In about one third the extremity was saved and in the other two thirds amputation ensued on an average only

after three years. It cannot be said what the fate of the extremities would have been without sympathectomy, but it was not seen to have any harmful effects. Sufficiently early sympathectomy would seem to be beneficial particularly for peripheral occlusions.

Expedients of vascular surgery intended to prevent amputation were only performed in four cases with fairly satisfactory results. Amputation of one gangrenous extremity was avoided, and amputation of the other three ischaemic extremities became necessary after 1.5 to 3 years. Among the reports supporting vascular surgery as a suitable measure is that by Taylor (1964) on 120 extremities with indication for amputation, about half of which could be saved.

Amputation at the thigh, particularly when it is bilateral, is a rather highly disabling operation. The present series contains a higher than normal percentage (89 % cf. Table 14 and 18) of such amputations and the amputation was bilateral in about one out of every six cases. The high frequency of these amputations was obviously caused by unfavourable experience with amputations at the lower leg, about one half of the lower leg stumps showed wound complications and reamputation was performed in about one third of them. As in some other amputation series reported (Record 1955, Dale and Jacobs 1962) the results obtained by usual techniques of operation were not satisfactory. Good results imply atraumatic or minitraumatic handling of tissues. Furthermore, the optimum length of the stump was always aimed at in the present series, independent of the vitality of tissues, and this is another partial cause of the wound complications and reamputations. Higher amputation at the lower leg might have been successful in many instances and furnished the advantage which even a shorter lower leg stump has over a stump after amputation at the thigh. According to previous observations, concentration of amputations or of their supervision to a few persons tends to improve the results as regards wound complications and to increase the number of peripheral stumps. Similar principles might have been conducive to more favourable results in the present series, too, considering that the amputations were performed by 55 different surgeons and there was no consistent supervision.

Both operative and hospital mortality were higher than in comparable series as a rule. This is thought to be mainly attributable to the high percentage of amputations at the thigh, which are mostly followed by higher primary mortality than those made at the lower leg (Table 18). In the present series, too, none of the 24 lower leg amputees died at

operation e g according to Harris et al (1951) lower leg amputees of equivalent age showed a primary mortality of only 6 %. Other causes that have to be considered include inadequate preoperative treatment it should be noted that more than one half of the patients (59 %) were anaemic (Hb less than 12 g per 100 ml) and that the mean duration of preoperative care was 4 4 days against 2—3 weeks as recommended e g by Record (1963)

As with observations made in series of general surgery patients (Andersen et al 1965) and of amputations (Veal 1938) in general the operative and hospital mortality was dependent on the patients age Those who died in the hospital had a mean age 8 years higher than those who survived the amputation for three years The former also showed a higher frequency of coronary diseases

In persons subjected to amputation on account of vascular insufficiency Thompson et al (1965) observed a higher rate of postoperative complications than in those whose amputation had been caused by malignant tumour or accident and also a higher rate after amputation at the thigh than at the lower leg They think that particularly after amputation at the thigh postoperative anticoagulant treatment is worth considering In the present series its appropriateness seems to be corroborated by the fact that autopsy revealed about one quarter of the deceased patients to have a thrombus of the coronary arteries as the basic cause of death and obliterative thrombosis of the common iliac arteries for instance occurred in about one half of those examined

The walking ability after amputation is perhaps most strongly affected by age (Schlitt and Serlin 1961 Lindholm 1964a) In the present series too the mean age of the prosthesis walkers was 65 years while that of the amputees confined to bed was ten years higher The height of amputation has an influence too since all six lower leg amputees were able to walk but no more than about two thirds of the patients subjected to amputation at the thigh and about one quarter of the bilateral amputees were walkers Age also plays an essential role in respect of working ability The three amputees who went to work were all younger than 55 years at the time of follow up examination

The extent of arteriosclerotic changes is also reflected by the causes of death 71 % of the deceased having a disease due to arteriosclerosis as the basic cause of death which is virtually the same figure as stated by Lindholm (1964a) 77 5 %

After amputation the arteriosclerosis progresses at a rather rapid rate

and amputees do not survive for very long As in the series of Hansson (1964), nearly one out of every two patients (41 %) was dead one year later and the remaining life expectancy of those amputated at an age *between 50 and 59 years was about 5 years i e 15 years less than for* a normal population of equivalent age The average life span of those subjected to amputation when they were 80—89 years old was only one month falling short of the normal life expectancy by 4—5 years

The observation can indeed be made that with the continuous increase of the average life span gangrene due to arteriosclerosis also increases and with unchanged indications of operation the amputations increase in frequency In the case of persons subjected to amputation on account of arteriosclerosis the diffuse changes associated with their basic disease and especially their high age make normal life possible *in rare instances while the majority (two thirds in the present series* 91 9 % in that of Lindholm 1964a) have to be placed in an institution or constant home care after amputation Accordingly all possible care in obviating amputation should be introduced at the gangrenous phase at the latest The situation might be changed either by revising the indications of amputation so that part of the amputations could be avoided by means of vascular surgery of which fairly favourable experience has been gained (Linden 1962 1967 Morris et al 1962 Lebedev 1964 Taylor 1964 Slatis 1965 Spencer and Winslow 1965) or by rendering the conservative treatment more efficient (Foley 1957 Heine et al 1964)

That expedients of vascular surgery were applied to rather a limited extent in the present series is revealed by a comparison with the series of Thompson Jr et al (1964) comprising 222 patients with vascular insufficiency who were subjected to amputation between 1952 and 1965 Of these 51 % had undergone lumbar sympathectomy and endarterectomy or a grafting procedure on the extremity involved before amputation in 16 % In the present series, the corresponding figures are sympathectomy performed in 55 % of the cases and some expedient of vascular surgery in 2 % only Even with the present indications of amputation the patients position may be improved merely by amputation technique If it is possible to increase the proportion of the less disabling lower leg stumps and in the most favourable case that of the even more peripheral stumps the operative mortality will decrease and the patients *chances of rehabilitation will improve*

XI SUMMARY AND CONCLUSIONS

In the present series comprising 184 patients subjected to amputation at the lower leg or at the thigh on account of arteriosclerosis the gradual development of arteriosclerosis has been studied on the basis of the symptoms of occlusion shown prior to amputation, of examinations at the time of amputation and of death certificates and autopsies. Attention has furthermore been paid to sympathectomy as a treatment precluding amputation, to the healing of the leg stump, to recovery after amputation and to the remaining life span.

Of the present patients 97 were operated at the Clinic for Orthopaedics and Traumatology of the University Central Hospital, Helsinki, in 1950—1963 and the amputations on 87 patients were performed in the former Hospital of the Finnish Red Cross during the period 19[illegible]—19[illegible]. The mean age at amputation was 68.7 years and men outnumbered women in a ratio of 3:2.

8 % of the patients were left with lower leg stumps and 92 % with upper leg stumps. Every fifth patient underwent bilateral amputation.

At the time of the follow up study 127 patients (69 %) had already died and 57 (31 %) were alive, of whom 38 (67 %) were subjected to follow up examination.

Symptoms of arterial occlusion had occurred prior to amputation in about three quarters of the series. The commonest symptom was intermittent claudication (60 %), while angina abdominis was most rarely encountered (4 %); angina pectoris was present in one out of every four patients (26 %), cerebral apoplexy in one out of every six (17 %) and symptoms of occlusion in the region of the neck and shoulders in about one out of every twenty. About one fourth had two or several simultaneous symptoms of occlusion. The intermittent claudication symptom mostly appeared first, on an average 2.7 years before amputation.

At the time of amputation 87 patients were examined by electrocardiography, which revealed changes in 69 %. Arteriographic exam

ination of 21 patients showed ample changes which were more frequent in the region of the pelvis and lower extremities on the side of the amputated extremity than on that of the extremity left intact In respect of pulsation the most notable differences between the amputated and contralateral extremity were observed in the most distal and the most proximal pulses of the extremity The possibility of renovascular hypertonia was considered to exist in about 15—22 % of the patients

Autopsies showed the pulmonary arteries to have been almost entirely spared from arteriosclerosis only 11 % of the autopsies revealing slight changes The arteries of the base of the brain were also normal in about one-fifth of the cases On the other hand there were hardly any large arteries of the pelvic region or superficial femoral arteries which had not been affected by arteriosclerosis they presented severe changes in about 50—70 % and cardiac infarction was established in 30 %

Sympathectomy had been performed on 93 extremities of 64 patients and 78 of these extremities (84 %) were subsequently amputated Sympathectomy was undertaken on the side of the amputated extremity at the intermittent claudication stage in 32 cases (41 %) and at the gangrene or rest pain phase in 46 (59 %) In the case of all the 15 extremities saved the sympathectomy had been made at the intermittent claudication stage and these patients had *no* occlusion in the pelvic region Sympathectomy was not seen to have any effect on the healing of the wound after amputation

The wound complications encountered were due to lowered vitality of the tissue and to local factors in about equal proportions whereas the contribution of infection was smaller The height of occlusion however exerted an influence in that the upper leg stump healed better when a peripheral occlusion was involved than in the case of an occlusion at a higher level

The primary operative mortality after amputations was 21 % All those *who died of the operation had been amputated at the thigh The deaths* that occurred within one year account for 41 % of the patients 71 % of all deceased patients had some disease due to arteriosclerosis as the *cause of death*

Of 58 patients subjected to follow up study 17 % walked with a prosthesis and 21 % were confined to bed The latter were on an average 10 9 years older than the prosthesis users

The following conclusions can be drawn on the basis of this study

1 Clinical symptoms of occlusion occurred prior to amputation in three quarters of the patients, the commonest among them (in 60 %) being intermittent claudication which had usually first appeared on an average, 2.7 years before amputation Obliterative symptoms from the coronary arteries occurred in about one quarter and symptoms of cerebral ischaemia in about one fifth of the cases Angina abdominis occurred most rarely (4 %)

2 Examinations of pulsation at the time of the first amputation revealed on the amputated side a higher frequency of occlusions in the pelvic region and the pedal pulses were absent in almost every instance whereas they were palpable on the contralateral side in about one out of every five cases According to arteriography the changes in the pelvic region and in the extremities were consistent with the numbers encountered in patients with ischaemia of the extremities but multiple occlusions and occlusions filling the entire lumen were 2—4 times more frequent on the amputated side than on the side which was left intact On the evidence of electrocardiograms as on that of the case histories cardiac infarction was seen to be present in about one out of every ten patients and the possibility of renovascular hypertonia existed in about one out of every twenty

3 At autopsy nine out of ten patients showed no arteriosclerotic changes of the pulmonary arteries and the cerebral arteries were normal in about one fifth In the highest and about equal number (1/2 to 2/3) there were severe changes of the coronary arteries abdominal arteries and arteries of the pelvis No normal findings at all were made in these respects

4 Lumbar sympathectomy had been performed on about one third of the patients In more than one half of the cases it had taken place when the disease had already progressed to the gangrene or rest pain stage and it was then fairly soon followed by amputation (after 1.4 to 3.5 months) The best results were recorded on sympathectomy made at the intermittent claudication stage when the occlusions in the extremities were peripheral in location

5 Wound complications were mainly caused by wrong assessment of the vitality of tissues local factors or incorrect amputation technique, while infections contributed less to their number Upper leg stumps healed better in cases involving peripheral rather than higher occlusions

6 Of the patients subjected to follow up examination about one-half were prosthesis users The average remaining life span after amputation was only about 1/5 to 1/4 of the life expectancy of an unselected population of equivalent age The cause of death was due to arteriosclerosis in 71 % and the commonest cause of death elicited by the autopsies (30 %) was attributable to sclerosis of the coronary arteries

ERRATA

Page	Line	for	read
8	1u	medical	medial
9	9u	lower leg	upper leg
10	6u	polyaethiology	polyaetiology
24	6	The exponent in e^{t} is out of line	
37	15	Tala (1966)	Tala et al (1966)
41	12u	slightly more than one-quarter (28 %)	about one quarter (23 %)
42	3u	state	states
48	20	Babbeley et al	Baddeley and Fulford
53	2u	hypertension	angiotensin infusion
57	15u	artery	aorta
61	13	five cases (17 %)	four cases (13 %)
65	5	reports	report
68	5	(Caption of Table 12) 78	93
71	9	Eraklis and Brownell	Fraklis and Wheeler
73	1	enumerates	enumerate
73	12	Eraklis and Brownell	Fraklis and Wheeler
73	3u	seevrity	severity
82	14	60–69	60–69 year
83	1	70–79	70–79 year
84	16u	219 amputees	219 amputations
91	8	had hypertonia or higher)	with hypertonia (RR 160/100 mmHg or higher) presented proteinuria not accounted for by pyelonephritis
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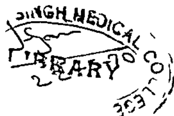
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ERKKI O KARAHARJU

DEFORMATION OF VERTEBRAE IN EXPERIMENTAL SCOLIOSIS

THE COURSE OF BONE ADAPTATION AND MODELLING IN SCOLIOSIS WITH REFERENCE TO THE NORMAL GROWTH OF THE VERTEBRA



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ACTA ORTHOPAEDICA SCANDINAVICA
SUPPLEMENTUM No 105

From the Orthopaedic Hospital of the Invalid Foundation
Helsinki Finland (Head Professor A Langenskiold M D)

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CONTENTS

I INTRODUCTION

Few if any orthopaedic diseases have received so much attention from investigators as scoliosis. Despite several decades of clinical and experimental research work, the cause of idiopathic scoliosis still remains unknown. Bone changes occurring in connection with scoliosis have been described, but the pathomechanism of the changes has escaped definite explanation.

Bone is hard, rigid tissue and these properties impose certain conditions on its growth. Bone formation cannot occur interstitially because it is unyielding tissue. "Remodelling" is a fundamental process in the growth of bone and causing continuous change of form during its growth. It is a normal dual process of growth, encompassing both apposition and resorption of bone. Remodelling changes are complicated by a process called osseous drift. Local formation of bone is associated with apposition to one surface and resorption from the opposite one. This in a way causes drifting of the bone.

External factors also influence the growth and modelling of bone. Especially during the growth period bone is sensitive to these influences. Many deformities of bone arise under the influence of external pressure. It is obvious that, at least to a certain degree, this is also the case in scoliosis.

In the Orthopaedic Hospital of the Invalid Foundation, problems associated with scoliosis have been studied for several years under the leadership of Professor *Anders Langenskiöld*. The present study forms a part of this wider series of investigations. The object of the study was to elucidate structural changes occurring in experimentally induced scoliosis and to investigate the pathomechanics of these changes. The so-called tetracycline method that has been generally accepted during recent years provided the prerequisites for following the structural changes of scoliosis as a dynamic event.

II REVIEW OF LITERATURE

I Growth of the normal vertebra

The growth of vertebrae and long bones is considered to be mainly similar. The vertebral body grows in length by means of the plates of epiphyseal cartilage on the cephalic and caudal surfaces. On the margin of the human vertebra there is a so-called ring apophysis which does not participate in longitudinal growth (*Bick*, *Bick* and *Copel*, *Bisgard* and *Musselman*, *Carpenter*, *Ehrenhaft*, *Haas*, *Hanson*, *Hollinshead*, *MacGowan*, *Roaf*, *Schmorl* and *Junghanns*).

The rate of growth in length of the back remains almost equal over the entire period of growth with the exception of the period of prepuberty during which it is accelerated. Between the ages of three and fifteen a thoracic vertebra grows about one millimeter a year (*Anderson et al*, *Duthie*, *Takkunen*). When the ossification in the ring apophysis is completed, vertebral growth is completed. Ossification of these apophyses occurs in girls at about 14 years of age, in boys at about the age of 16 (*Calvo*, *Risser*). The growth in length of the vertebrae has been quantitatively studied by means of radioactive isotopes (*Jee* ...). In the epiphyseal plates of pigs and rabbits the growth is stronger interiorly (*Ponlot*, *Sulig*). Such epiphyseal plates do not exist in humans.

According to *Larsen* and *Nordentoft* no apposition occurs in the posterior part of the body after five years of age. By analogy with the growth of the cranium the vertebral arch grows rapidly between the ages of 3 and 5, but by the age of one year the parts of the arch have already been united by bone tissue in the thoracal spine (*Ottander*). The neural arch does not become enlarged in all directions; while enlarging it migrates away from an "imaginary point" which would be located in the dorsal part of the vertebral body (*Lacroix*, *Ponlot*).

The vertebral body and the arch are joined together by the so-called neurocentral epiphysis which closes at the age of 3 to 6 years. The cartilaginous pillars of the epiphysis are bipolar, and the growth thus occurs in two directions, towards both the body and the arch (*Knutsson*, *Minciro*, *Pacher*, *Rouve* and *Rocher*).

2 Modelling of bone under pressure

The fact that pressure may influence the growth of bone has been known for centuries As a rule growth in length occurs in the epiphyseal line The increased length is attained through the multiplication of cartilage cells which are later converted into bone by enchondral ossification (*Siffert*) Growth in thickness on the other hand occurs through the addition of new bone to bone surfaces

The generally accepted view of the nature of the external form and of the internal architecture of bone is expressed in *Wolff's* law usually stated in the following form Every change in the form and function of a bone or in function alone is followed by a certain change in the external conformation and in the internal architecture in accordance with mathematical laws (*Carey Geiser* and *Trueta Jansen Townsley Weinmann* and *Sicher*)

Pressure has an effect on the growth in both length and thickness of the bone

Pressure stimulates appositional bone growth Thus for instance increased weight bearing of the tibia will result in increased thickness and density in the middle of the shaft Fractures healed in faulty positions have a tendency to straighten This straightening is effected by the deposition of appositional new bone along the concavity while bone is being resorbed from the convex side (*Arkin Bell Carey Evans Frost Gelbke Ghillini*)

Pressure parallel to the axis of the epiphyseal growth affects the rate of such growth Increased pressure in this direction will inhibit growth while decreased pressure will to some extent accelerate it This relationship was recognized in 1862 by *Hueter* and *Volkmann* and it is called the *Hueter Volkmann* law Pressure acting obliquely to the direction of growth results in deflection of the direction of such growth with lateral or spiral displacement of the newly laid-down bone as the consequence (*Alexander Arkin* and *Katz*)

According to *Maass* pressure effects the entire bone so that the intensity of growth will not change If pressure inhibits the growth in a certain direction the bone will compensatorily grow without quantitative alternations in a direction that is free from pressure

Several experimental studies have been performed on the effect of pressure on epiphyseal growth It has been shown that compression by means of a wire loop or staples will entirely arrest epiphyseal growth Quantitative measurements as to the magnitude of the pressure necessary for this have been made (*Arkin* and *K* and *Clarke Blount* and *Zeier Gelbke Ghillini Haas Nachlas* and *Smith* and *Cunningham Strobino et al*)

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the growing vertebra. We may assume that this increased weight on the ventral part of the vertebral body is the stimulus which induces the constructive material available to collect at this part of the vertebra: when the sagittal diameter of the vertebra increases, the supporting points approach the load line and static improves. This statement pertaines the vertebral growth in the ventral direction.

In their experimental study on the effect of pressure on the tibia *Arkin* and *Katz* were able to demonstrate interesting changes both in the epiphysis and in the diaphyseal area. After six weeks of immobilization in a plaster cast it was found that growth was retarded on the side under pressure. On the opposite side growth was accelerated. On the side that had been under pressure trabeculation was found to have increased in the shaft of the tibia. This was an illustration of a paradox between *Wolff's* and *Hueter-Volkmann's* laws. Increased pressure in the direction of growth in length results in increased growth in thickness but reduced growth in length.

3 Structural changes caused by scoliosis

Idiopathic scoliosis is not a bending of the spine in the frontal plane due to irregular growth, but rather a most complex deformity involving lateral displacement of the vertebra, rotation and multiform thoracic deformities (*Cobb, McCarroll* and *Costen*).

Scoliotic structural changes have been described in rather great detail in the literature for over a century. Several experiments on animals have resulted in deformities resembling scoliosis in man, lending support to concepts of structural changes.

The following structural changes in the scoliotic vertebra have been observed:

- the vertebra is lower on the concave side and higher on the convex side
- the vertebral body is deformed
- the bone structure of the vertebral body is denser on the concave side and usually resorption is observed on the convex side
- in the intervertebral disc the nucleus pulposus is displaced towards the convex side
- the arch on the concave side is short and clumsy, whereas on the convex side it is longer
- the spinous process has turned towards the concave side
- the neuro-central epiphysis is open on the concave side and its growth is disturbed on the convex side
- the neural canal is narrowed on the concave side
- there is atrophy of the epiphyseal plates on the concave side

- on the concave side proliferation of the epiphyseal cartilage is reduced or absent and the cartilage bar formation is deformed
- on the convex side the growth of the epiphyseal cartilage is accelerated irregularities have also been found in this area

(*Bade Beadle Deutschlander Imhauser Jaroschy Kleinberg Lange Lorenz Lovett Michelsson Miles Muller Nicoladoni Ottendorff Pacher, Reiner* and *Werdorff Roaf Schanz Schulthess Stilwell Unger*)

Méry (1707) was the first to draw attention to the rotation and torsion of the vertebrae observed in a scoliotic back (*Valentin*) Rotation means that the vertebrae in the area of scoliosis are rotated in relation to each other so that the body turns towards the convex side Torsion especially in German literature indicates a vertebral asymmetry that is formed in association with and as a consequence of rotation On the basis of studies with cadavers mechanical models and mathematical deductions the conclusion has been reached that the lateral bending in extension of the spine is associated with rotation of the vertebrae towards the concave side and lateral bending in flexion with rotation directed towards the convex side Since lateral bending is as a rule associated with rotation no rotation will occur without lateral deviation (*e Lesser Lovett Reiner* and *Werdorff Steindler*)

Rotation in apical vertebra (the most laterally displaced) is an integral part of scoliosis that becomes aggravated when the curve increases The joints of the articular processes are located laterally and posteriorly in relation to the centre of the vertebra Therefore the spinal column cannot yield in the direction of the joints without wheeling partially around with the result that the vertebra turns obliquely towards the convex side The more posteriorly the articular processes are situated the more severe is the rotation of the apical vertebra and the earlier it appears This is the case e g in scoliosis of the lumbar spine Rotation reduces pressure on the vertebral end plates on the concave side Therefore the effect of pressure on the end plates is less in the lumbar area where rotation appears early If the articular processes are situated less posteriorly as in the thoracic spine rotation of the apical vertebra appears later It has been supposed that the wedged vertebra that forms in a scoliotic back increases the tendency towards rotation (*Arkin Carey Lovett Ponseti* and *Friedman Risser Steindler*)

When a healthy trunk is turned maximally rotation from 1° to 4° occurs between each two adjacent vertebrae (*Lindahl* and *Raeder*) The greatest changes have been considered to occur in the disc (*Jentschura Somerville*) the centre of the rotation being at the site of neurocentral epiphysis (*Ottander*)

At the limit of rotatory excursion the rotary force affects the vertebral body and causes structural changes or torsion

4 Pathomechanism of scoliotic structural changes

The normal spine tends to return as closely as possible to the mid line over the sacrum This is called the straightening tendency of an angulated vertebral column A scoliotic spine i e the involved vertebrae straightens to the extent permitted by the soft tissues on the concave side As the scoliosis progresses and if no other forces are involved the curve will eventually reach the point where the lateral soft tissues on the convex side are maximally stretched and the compression on the concave side cannot increase any more In this situation other forces are also at work among them the g r o w t h o f t h e v e r t e b r a (*Risser*)

Since the beginning of the 19th century the pathomechanism of the structural changes caused by scoliosis has been studied In 1824 *Bampfield* observed that scoliosis appeared only during the growth period of the spine He expressed the view that scoliosis is due to increased growth on one side of the vertebral bodies concurrently with resorption caused by pressure on the opposite side It is generally agreed that scoliosis becomes aggravated only during growth (*Calvo Duthie*)

Of the many structural changes caused by scoliosis referred to previously the *wedge formed* vertebrae have engaged the attention of investigators most In considering the development of wedged vertebrae the fundamental view has been that when the spine is bent laterally pressure has increased on the concave side and correspondingly decreased on the convex side A wedged vertebra in scoliosis does not develop in an adult the process of wedge forming stops when the growth of the spine ceases These facts would suggest that a deformity which appears and becomes aggravated only during the period of growth must be related to growth

In the section Modelling of bone under pressure the laws according to which modelling occurs were surveyed In the case of a scoliotic wedged vertebra attention has almost always been paid to effects consistent with *Hueter Volkmann*'s law According to this increased pressure on the concave side and decreased pressure on the convex side result in retardation of growth on the concave side and on the other hand in its acceleration on the convex side of the epiphyses (*Arkin Bick Bisgard and Musselman Blount* and *Clarke Haas Lindemann Michelsson Moser Muller Rathke*)

Maass has presented a concept of the mechanism of development of the wedged vertebra that deviates somewhat from that presented above According to him quantitative growth has not changed but it occurs on the concave side in a direction devoid of pressure This results in increased density of the bone structure on the concave side and the development of a wedged vertebra

The increased density of the bone structure on the concave side has generally been explained by *Wolff's* law that pressure augments bone growth (*Arkin Deutschlander, Muller Schanz*) *Stilwell* has given as his opinion that the thickening is due to the fact that on the concave side the periosteum draws away from the compact bone like a taut bow string and new bone formation occurs in and along the elevated Sharpey fibers of the periosteum

In the same way the decreased trabeculation found to occur on the convex side has been said to be caused by reduced pressure according to *Wolff's* law In *Stilwell's* view however the periosteum is involved even here being stretched and tense at the convexity and due to pressure bone and cartilage tissues are resorbed

Less attention has generally been paid to the pathomechanism of vertebral rotation Opinions about the origin and direction of torsion differ Some of the rotation has been said to occur by means of vertebral torsion In the scoliotic apical vertebra the body is squeezed over or deflected to the convex side The opinion has been expressed that muscles are not involved in the appearance of torsion and that this passive plastic deformation is due to the wedged vertebra (*Arkin Muller*) According to work done by *Appleton*, muscle action results in torsional deformation but this mechanism has not been explored *Arkin* has found experimentally that pressure applied obliquely to the axis of epiphyseal growth will change the direction of such growth as has already been mentioned above Thus the torsional deformation in scoliotic vertebrae is caused by the deflection of growing epiphyseal cartilages in a manner analogous to the deflection of water entering a flowing stream — as *Arkin* says

The neurocentral epiphyses have also been considered to be implicated in the development of torsional deformity owing to the asymmetric growth of these paired epiphyses in a scoliotic vertebra (*Knutsson Mineiro Schulthess*)

Changes in the intervertebral discs have been largely regarded as mechanical As a result of the lateral deviation in the spine the intervertebral spaces have become narrowed on the side of the concavity and widened at the convexity a consequence of this being that the elastic nucleus move over to the convex side (*Bick et al*)

The structural changes in scoliotic vertebrae have as a rule been considered secondary (*Bick et al Lovett Michelsson Stilwell*) although views as to their primary nature have also been presented (*Knutsson McCarroll* and *Costen, Mineiro Ottander Roaf*)

Numerous attempts have been made to solve the problems involved in scoliosis by means of animal experiments The majority of animal experiments have been directed towards elucidating the etiology of scoliosis *Michelsson* has given a thorough review of these experiments in his work

Scoliosis has been effected by resecting the epiphyses and preventing growth by means of stapling the end plates (*Bisgard* and *Musselman* *Ghillini* *Haas* *Moser* *Nachlas* and *Borden*) The destruction of the neurocentral epiphysis on one side has resulted in the development of scoliosis (*Ottander*) *Pacher* was able to produce scoliosis by simultaneously resecting the neurocentral epiphyses and the end epiphyses Scoliosis has also been effected by preventing epiphyseal growth experimentally by means of X ray treatment or radioisotopes (*Arkin et al* *Arkin* and *Simon* *Engel*)

5 Use of tetracycline in bone studies

The fixation of tetracycline in living tissues has been known for years (*Bottinger* *Helander* and *Bottinger*) The observation by such investigators as *Milch* *Rall* and *Tobie* that tetracycline is deposited in mineralizing bone has stimulated the use of this phenomenon in studying bone physiology (*Frost*)

Tetracycline labelling of bone possesses the following characteristics any currently available tetracycline administered in vivo by any route will be deposited in newly formed and mineralizing bone cartilage and teeth Most tissues will be stained as a result of tetracycline administration Within 48 hours of the withdrawal of the drug adventitious tetracycline disappears from the bone and the remaining tetracycline is present only in the labelled bone and calcified cartilage Tetracycline so deposited will appear as yellow fluorescence in proper sections under ultraviolet light (*Bailey* and *Levin* *Bottinger* *Frost* *Frost et al* *McLeay* and *Walske* *Plaza Roca* *Tubaro*)

Tetracycline labelling is comparable to the use of isotopes and alizarin but possesses none of the drawbacks of these agents The tetracycline label is permanent in that it remains in situ until the labelled bone is resorbed Although some fading occurs there is no diffusion of the agent into the surrounding tissues (*Frost* *Frost et al* *Kelly et al* *McLeay* and *Walske* *Milch et al* *Owen*)

Tetracycline has been found to pass through the placenta and to become deposited in the growth zones in the foetal skeleton Administered during the early period of growth it has been found to cause growth and developmental disturbances in bones especially in teeth This was verified by tests in vitro (*Bevelander et al* *Carter* and *Wilson* *Cohlan et al* *Filippi* and *Mela* *Hakala* and *Makela* *Saxen* *Wallman* and *Hilton*) During later periods of growth however the drug exerts no adverse effects on bone formation and mineralization (*Frost* *Frost et al* *Ilsen* and *Urist*) Several examples of the affinity of tetracyc

line to tissues undergoing necrobiotic changes have also been published (*Kornamo* and *Niemi* *Milch et al* *Mustakallio* *Rall et al* *Tapp et al* *Whitmore et al*)

The exact nature of tetracycline fluorescence and fixation is not known Several investigators have however reached the conclusion that the process involved is the binding of structurally unaltered tetracycline with calcium probably by means of a peptide bond (*Finerman* and *Milch* *Hakkinen* *Ibsen* and *Urist* *Kohn* *Plaza Roca* *Shils* *Urist* and *McLean*)

III MATERIAL AND METHODS

1 Experimental animals

The vertebrae of both pigs and rabbits differ little in fundamental structure from those of man (*England*, *Weaver* and *McKean*). On the cranial and caudal surfaces of the vertebrae the animals mentioned have epiphyseal plates. In the rabbit and pig vertebral growth occurs in the same way as in man (*Amato* and *Bombelli*, *Beadle*, *Ellenberger* and *Baum*, *Krause*, *Smith* and *Walmsley*).

Rabbits and pigs were used as test animals. They were selected for the study mainly from the age groups in which growth was most rapid, because scoliosis is particularly a disease of the growth period. Some older animals were used as controls. No attention was paid to their sex. The diet and management was uniform. A total of 168 test animals were used: 121 rabbits and 47 pigs. As is seen from table 1, a scoliosis provoking operation was performed

TABLE 1 – *Material used and investigations performed*

	Number of animals	Investigations			
		X-ray examination	Histological examination	Tetracycline examination	Study on rotation
Rabbits					
Study on normal growth	31	121	24	27	
Study on scoliosis	78	254	62	62	
Died during operation	12				
Totals	(121)	(375)	(86)	(89)	
Pigs					
Study on normal growth	15	82	7	15	2
Study on scoliosis	30	201	15	30	6
Died during operation	2				
Totals	(47)	(283)	(22)	(45)	(8)
Totals	168	658	108	134	8

upon 78 rabbits and 30 pigs Thirty-one rabbits and 15 pigs served as a control series and the normal vertebral growth was also studied from them Because the rabbit is small as a test object and especially because its vertebral body is filled with a very coarsely porous spongiosa analyses of the results was difficult This difficulty became especially evident in the tetracycline technique to be reported later It was for this reason that pigs were used as experimental animals in the later part of the study

2 Surgical procedures

Anaesthesia The rabbits were operated on under local anaesthesia with 0 25 % Xylocain exadrine® The pigs were anaesthetized by means of open mask using trilene

Types of operation Because human scoliosis is mostly convex to the right all scoliosis provoking operations were performed on the right Resection of 5 ribs was performed on all rabbits The intercostal nerves were cut simultaneously Four different kinds of surgical procedures were performed on the pigs (Table 4) Costal resection was performed on 18 pigs The number of resected ribs ranged from 5 to 8 Costal resection supplemented with fixation by a dacron thread on the left was carried out on eight pigs Costal resection and hemilaminectomy was performed on one pig Dorsal ligaments of the 8th to 12th ribs were severed in three pigs

Technique of operation A longitudinal dorsal skin incision was made over the operative area The right side of the spinous processes and arches was freed in the midline and the ribs to be removed were freed subperiosteally The costae were resected so that about 1 5 cm in the rabbits and about 8 cm in the pigs were removed from the dorsal end of the ribs The most dorsal part of the resected costae was carefully freed and removed entirely The intercostal nerves were identified and a piece of about one cm was removed from them In fixation procedures the left side of the spinous processes and vertebral arches as well as of the dorsal ends of the ribs was also freed The fixation was effected by attaching the costa and spinous process to each other so that a dacron thread was threaded first under the rib and then in a figure-of-eight suture through a hole drilled in the spinous process The thread was tied at a moderate tension The precise level of fixation will be seen from table 4 In one of the pigs in which costal resection was carried out, the right side vertebral arches were also removed from the area shown in table 4 In three operations all the ligaments attached to the dorsal ends of the costae listed in table 4 were severed

Operative complications Pneumothorax was produced in almost all the operations on rabbits In spite of this operative mortality was comparatively low 12 rabbits dying during surgery In the operations on pigs cardiac arrest caused apparently by trilene was the cause of operative death in two cases Pneumothorax did not develop in pigs

Antibiotic prophylaxis The test animals which were examined by means of the teracycline method received no other antibiotic protection Those in whom this examination was not performed received 100 000 units of procain penicillin intramuscularly Streptomycine powder was applied to the wound in all operations

3 Methods of study

All examined spines were prepared and examined visually before any other studies were undertaken

X-ray examination

X ray films were taken of all the animals employed in the series Antero posterior roentgenograms with back against the casette were taken of both rabbits and pigs and lateral exposures were taken when the animal was lying on its right side The films were taken without anaesthesia by holding the animals by their limbs The first X ray was taken immediately after operation The degree of scoliosis was measured from the X ray films by determining the curvature in accordance with the direction of the vertebral end plates In all 638 X ray examinations were made

Histological examination

Histological examination was performed on 86 rabbits and 22 pigs Of the animals 62 rabbits and 15 pigs were scoliotic the rest were normal A different number of slices were taken from each animal The preparations were fixed in 10 per cent solution of formalin and decalcified in 32 per cent solution of EDTA whose pH was between 7 2 and 7 4 Following decalcification they were dehydrated in a rising series of alcohols The specimens were mounted in paraffin and cut in the ordinary way using the Leitz sliding microtome No 1300 The slices were taken in frontal sagittal and cross planes and stained with Van Gieson haematoxyline eosine The histological preparations were photographed on Adox black and white film using the Leitz Ortolux microscope

Tetracycline examination

As mentioned above the use of tetracycline in investigations is based on the fact that when injected into an animal it is deposited in newly formed bone labelling the bone structure at that particular moment On the basis of growth that had occurred in relation to this labelled area it was possible to follow normal growth as well as the development of scoliotic structural changes The use of tetracycline limited the time of observation of the objects of study because the bone labelled by it becomes resorbed later The post-operative survival time had therefore to be limited so that the labelled bone structure was still visible in the preparation

The spongiosa of the vertebral body of the rabbit is very large-celled Therefore when as a result of growth the tetracycline line has moved from the area of the compact bone to that of the spongiosa it is hardly visible — at least it is not possible to obtain satisfactory registrations on films It was mainly because of this that the study which was started with rabbits was completed with pigs

Tetracycline (Oxytetracycline Terramycin® Pfizer)) was administered intramuscularly immediately prior to operation in doses of 500 mg on three successive days to pigs and in doses of 100 mg on two successive days to rabbits In a few cases the tetracycline injection was repeated once or several times after the pre operative injection The specimens were thoroughly cleaned by removing all soft tissues They were either examined immediately or preserved at 0°C In the case of pigs the tetracycline preparations were made by means of an ordinary close toothed saw and of rabbits by means of a rotating blade mounted on a Reko Dental drill The specimens were cut in frontal sagittal and cross planes The cross slice was sawn in the cross plane in relation to the vertebra concerned The surfaces that were to be examined were ground smooth by means of emery paper The preparations were examined by using two OPTON fluorescence lamps with Osram HPO 75 mercury high pressure bulb equipped with a UG 1 filter as the source of light The photographs of the preparations were taken by means of a Leitz Aristofot apparatus in reflected light using the same lamps and a Wratten 2B and CC20 R filter in the objective The photographs were taken on Agfa ct 18 film and the copies of the diapositives were made by Kuvasampo Oy

Rotatory study was performed on 8 scoliotic pig preparations The method of study is given in connection with the results

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) The author is much indebted to Pfizer for kindly supplying the Terramycin used in this study

Operative complications Pneumothorax was produced in almost all the operations on rabbits In spite of this operative mortality was comparatively low 12 rabbits dying during surgery In the operations on pigs cardiac arrest caused apparently by trilene was the cause of operative death in two cases Pneumothorax did not develop in pigs

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Histological examination

Histological examination was performed on 86 rabbits and 22 pigs Of the animals 62 rabbits and 15 pigs were scoliotic the rest were normal A different number of slices were taken from each animal The preparations were fixed in 10 per cent solution of formalin and decalcified in 52 per cent solution of EDTA whose pH was between 7 2 and 7 4 Following decalcification they were dehydrated in a rising series of alcohols The specimens were mounted in paraffin and cut in the ordinary way using the Leitz sliding microtome No 1300 The slices were taken in frontal sagittal and cross planes and stained with Van Gieson haematoxyline eosine The histological preparations were photographed on Adox black and white film using the Leitz Ortolux microscope

In pictures taken in ultraviolet light the bone labelled by tetracycline appears as yellow fluorescence. In the corresponding drawing this is illustrated by the blue line. The area labelled by tetracycline thus indicates the shape of the vertebra at the moment of injection. The non fluorescent bone around it has grown later.

In cross sections it will be seen that growth on the outer surface of the vertebra has occurred almost symmetrically. In the neurocentral epiphysis growth proceeds symmetrically towards both the body and the arch.

Sagittal and frontal sections reveal that the vertebra has grown to an equal extent in both the cranial and caudal epiphysis. In the lateral and ventral directions the growth has occurred appositionally. The epiphyseal plates have grown symmetrically with the rest of the vertebra in the cross plane but no growth worth mentioning has occurred in the craniocaudal direction.

The observations obtained lend support to previous views of growth of the vertebra. The vertebrae of rabbits and pigs grow mainly in the same way as those of human beings.

Growth mechanism of the neural canal

The neural canal forms a specific independent component of the vertebra. As was mentioned above its growth ceases considerably earlier than the growth of the rest of the vertebra, i.e. simultaneously with the cessation of growth of the skull. It became apparent in the present study that the growth of the neural canal occurs in a slightly different way depending on whether the neurocentral epiphysis is closed or not.

Twenty one rabbits were used. Tetracycline was injected into the animals. They were killed at different intervals. The vertebrae to be examined were cut in cross plane from the middle of the diaphysis and the preparations were examined under UV light.

The observations were similar in all the preparations examined. Immediately following the injection tetracycline was incorporated in the lateral side of the compact part of the neural canal.

The way of growth before closure of the neurocentral epiphysis is shown in figure 6 a. The tetracycline line may be seen located asymmetrically in the compact part of the neural canal. Apposition and resorption have occurred asymmetrically. Some growth has occurred in the neurocentral epiphyses.

Figure 6 b reflects the way of growth following closure of the epiphysis mentioned above. The tetracycline line is situated symmetrically in the compact part of the neural canal, a fact that would suggest that apposition and resorption have occurred symmetrically.

Figure 7 demonstrates schematically the growth mechanism of the neural canal Thicker lines corresponding to the tetracycline line in the preparation indicate the shape of the neural canal at the moment of injection

The neurocentral epiphyses are symmetrical Together they form a blunt angle opening in the ventral direction Maturation of the cartilaginous cells in this epiphysis does not always occur perpendicularly to the epiphyseal line (Figs 3 b and 4 b)

Because of the bony structure of the area it is difficult to examine the dorsal part of the vertebral body in the rabbit On the other hand in the vertebrae of pigs (Fig 5) it is possible to observe apposition in the dorsal part of the body proportional to the growth that has occurred in the neurocentral epiphyses This may allow the conclusion that the neural canal does not become enlarged in the ventral direction to any degree worth mentioning

2 Studies on scoliotic rabbits

Development of scoliosis in rabbits

The development of scoliotic curvature in rabbits is seen in table 2 as a function of the post-operative time A total of 234 X-ray examinations were performed The scoliotic curvature was measured from the ends of the scoliotic area on the basis of the angle formed by the end plates of the vertebrae

As may be seen from the table immediately following the operation a rather severe scoliosis was often noticed the most common range of the scoliotic

TABLE 2 – *Extent of scoliosis in rabbits*

Time after operation in days	Scoliosis in degrees					
	0–19	20–29	30–39	40–49	50–59	60–
Immediately after operation		2	13	18	28	
Under 9	2	2	4	2	11	
10–19	1	3	3	5	18	
20–29	1	4	5	6	11	
30–39	1	2	2	7	1	
40–49		1	2	1		
50–69				1		
70–100		1	1	1		

curvature being 55°–59°. A part of these later straightened to some extent. The majority of the scolioses investigated, however, either remained unchanged or progressed regularly. The scoliotic curvature progress as a function of time

Structural changes caused by scoliosis

Scoliotic structural changes were examined histologically in 62 rabbits and 15 pigs. On account of the large series and variations in observation time the histological changes found in rabbits were subjected to closer scrutiny.

Figure 25 shows that by means of tetracycline and histological sections taken from the same scoliotic vertebra the newly formed bone on the concave side was found to be structurally different from normal. The word trabeculation is used to illustrate this altered bone structure (*trkin and kat*). The compact bony layer of the trabeculated area is more thick and porous in comparison with normal compact bone and that on the convex side.

Figure 18 gives a schematic description of the areas in which the histological alterations which eventually occurred were systematically surveyed. These include trabeculated bone structure (1, 2, 3), changes in the neurocentral epiphysis on the side of the convexity (4), asymmetry of the neural canal (5) and alterations in the end epiphyses (6).

It was found that structural alterations in scoliotic vertebrae appeared quite rapidly after operation. The intervertebral disc had already been displaced towards the convexity a few days following the operation. This is not, however, considered an actual structural change but on the basis of other studies it is rather regarded as a mechanical phenomenon due to lateral deviation of the spine (*Bick et al.*). Figure 8 shows thickened bone structure on the concave side of the vertebral body even 5 days after the operation. Nine days post operatively (Fig. 9) the trabeculation on the concave side of the vertebral body is clearly visible. Asymmetry of neurocentral epiphyses appears in a mild form – this epiphysis is broader on the concave than on the convex side. 15 days after operation (Fig. 10) the changes are already clearly visible. Alterations may be observed in the vertebral body and neurocentral epiphyses and trabeculation has also appeared in the area of the arch. Changes in the most severely deformed vertebrae are shown in figures 11 and 12.

The scoliosis provoking operation performed on the oldest rabbits also resulted in structural changes. As was mentioned above, all the animals subjected to histological scrutiny were operated on during the growth period. Figure 13 presents a vertebra deformed by scoliosis taken from a rabbit operated on at the age of 76 days. At the time of operation the neurocentral epiphyses were

closed Nevertheless definite changes may be observed in this section of the vertebral body

Histological alterations in scoliotic vertebrae are most pronounced in the area of the apex The radiological status and cross sections of various vertebrae of the scoliotic area are presented in figure 14 It will be seen that in the apical vertebra the neurocentral epiphyses are closed on both sides Strong trabeculation both in the body and in the arch may be observed at the concavity The neural canal is asymmetric and there is trabeculation on the convex side of the neural canal These changes become milder as the normal vertebra is approached In the last section of the series of pictures the vertebral structure is almost normal

Figure 15 illustrates the radiological development of the scoliosis of rabbit No 81 as well as the scoliotic changes found in the cross section specified at the apex Definitely increased trabeculation may be observed on the concave side in both body and arch The neurocentral epiphysis is partly closed on the convex side The neural canal is clearly deformed towards the concavity Trabeculation is increased on the convex side of the neural canal

In figures 16 and 17 scoliotic changes are illustrated as frontal sections Definitely increased trabeculation on the concave side may be seen in all preparations Figures 16 c and 17 c demonstrate the changes in the end epiphysis on the concave side The cartilaginous structure is irregular and the normal palisade formation is disturbed in comparison with the epiphyseal structure on the convex side (Figs 16 b and 17 b) There are irregularities in the cartilaginous cells of the end epiphyses on the concave side and as may be seen from figure 17 c the cartilaginous cellular layer is thicker on the concave side There are more cells in this area and indistinct palisade formation is more than normally directed towards the concavity This change is most distinctly apparent in figures 22 f to h which show a vertebra from a scoliotic pig

Figure 18 depicts those areas where changes were found in the scoliotic vertebra of a rabbit These changes are classified in table 3 The changes were observed in both cross and frontal sections in 62 rabbits The severity of the changes was assessed on the basis of the following criteria The numbers refer to the diagram in figure 18

(1) Changes in the vertebral body at the side of concavity

0 = No changes

I = Moderate trabeculation (Fig 10)

II = Severe trabeculation (Fig 14 c)

(2) Changes in the concave side of arch laterally

0 = No changes

I = Moderate trabeculation (Fig 14 c)

II = Severe trabeculation (Fig 12)

(3) Changes in the convex side of arch medially

0 = No changes

I = Moderate trabeculation (Fig 14 d)

II = Severe trabeculation (Fig 14 e)

(4) Changes in the neurocentral epiphysis on the convex side

0 = No changes

I = Epiphysis narrowed and cartilaginous cells irregularly placed (Fig 14 f)

II = Epiphysis partly or totally closed (Fig 15)

(5) Deformation of the neural canal

0 = No changes

I = Neural canal slightly asymmetric towards the concavity (Fig 12)

II = Neural canal severely asymmetric towards the concavity (Fig 15)

(6) Changes in the end epiphysis on the concave side

0 = No changes

I = Cartilaginous cells irregularly placed and cartilaginous palisade formation disturbed (Fig 17 c)

II = Cartilaginous cells very irregularly placed and cartilaginous palisade formation disturbed (Fig 16 c)

From table 3 it can be seen that in the vertebral body changes on the concave side i e increased trabeculation appear most generally and are the first to be observed It has been possible to establish this even a few days after operation The next common alteration is increased trabeculation in the lateral part of the concave side of arch Almost simultaneously changes appear in the neurocentral epiphysis on the convex side with disarrangement of the cellular structure This is followed by additional trabeculation on the medial part of the convex side of arch, and the neural canal becomes asymmetric The changes occurring in the end epiphyses al o appear rather early in the form of irregular cellular structure on the concave side These changes are however comparatively slight in the early stages and they do not progress so severely as the other alterations observed In none of the sections examined was the cellular structure on the concave side of end epiphysis totally destroyed

As can be seen from the table changes occurred somewhat more rapidly and clearly if the operation was performed at an earlier age Definite histological

TABLE 3 – *Histological changes in rabbits associated with scoliosis (Explanation of the signs in text)*

Age at the time of operation in days	Post operative time in days	Areas and severity of the histological changes – Fig 18																	
		(1)			(2)			(3)			(4)			(5)			(6)		
		0	I	II	0	I	II	0	I	II	0	I	II	0	I	II	0	I	II
Under 29	0–19	1	2	2	3	1		2	2		3	2		1	3	1	3		
	20–39		2	2	2	2		3	1		2	2			3	1	1	1	
	Over 40			3		1	2		2	2			3		1	2		2	
30–39	0–19	2	3		2	3		4			2	3		2	3		2		
	20–39		3	3	3	1		5	1		4	2		4	2		2	2	
	Over 40		2	3	1	3	1	1	3	1		3	4	1	4		1	3	1
40–49	0–19	4	3	3	3	5	2	5	3		3	5	2	4	5	1	3	2	1
	20–39		2	3	1	3	1	1	4		1	3	1	1	3	1	1	1	1
	Over 40		1	4		3	2	2	3	1		2	3		3	2	2	2	
50–69	0–19	1	1		1	1		1	1		1	1		1	1		1	1	
	20–39	1	1	1	1	1	1		2		2	1		1	2		1	2	
	Over 40			1		1			1				1			1		1	
Over 70	0–19		1			1			1		1			1				1	
	20–39		2			1	1		2		2				2			1	
	Over 40		1	1		2		1	1		2				2		1	1	

changes were also found in older rabbits The changes progress as a function of the post operative time

A casuistic table of the series of rabbits operated upon is presented before the illustrated appendix on page 55 (Table 7)

3 Studies on scoliotic pigs

Development of scoliosis in pigs

The series of pigs operated upon is presented in table 4 The animals were arranged according to the greatest measured scoliotic curvature and according to operative technique

The severest scolioses occurred in the group in which both costal resection and fixation were performed In this group the maximum curvature was almost always attained towards the end of the observation period at worst it was 102°

TABLE 4 — *Scoliosis provoking operations in pigs*

P g No	Ope at e techn que				Least and g atest scol os s n deg ees			
	Resect on of th dorsal end of th b on th r ght				Least	Post operat ve time in d ys	G eatest	Post-operat ve t me n days
16	8—13	(6)			5	24	5	94
14	8—14	(7)			0	104	9	36
8	7—11	(5)			5	78	11	57
4	7—11	(5)			5	84	12	10
15	8—12	(5)			13	24	13	94
6	7—12	(6)			0	78	13	57
10	6—12	(7)			3	35	15	51
3	7—11	(5)			13	74	16	15
9	6—11	(6)			13	35	17	117
1	7—11	(5)			11	49	18	69
7	8—12	(5)			5	83	19	67
13	7—13	(7)			16	104	20	79
21	8—13	(6)			15	65	21	98
2	6—10	(5)			11	49	21	69
18	5—12	(8)			13	23	23	81
11	8—13	(6)			15	43	25	119
5	8—12	(5)			20	67	29	83
17	6—11	(6)			13	35	35	81
			Resect on of th dorsal nd of th b on the ght and f x t n w th dac on th ad Th-Th and Th-Th on the l ft					
			costa—sp os proc ss	costa—sp nos s process				
22	8—12	(5)	7—10	13— 9	35	85	37	118
19	8—12	(5)	7— 8	13— 8	31	111	37	65
26	6—11	(6)	5— 9	12— 8	38	15	47	109
24	7—12	(6)	6— 9	13—10	37	47	48	137
25	8—13	(6)	7—10	14— 9	39	50	50	72
23	8—12	(5)	6— 8	13— 7	42	82	53	82
27	8—12	(5)	6— 9	13— 7	83	58	84	115
28	7—12	(6)	5—10	13— 7	90	58	102	115
	Resect on of th dor al nds of the bs on the ight and hem l m nectomy n th gh Th 7 to 11							
20	7—11	(5)			11	39	31	111
	T a ect on of th l game ts ttached to the dorsal end of the b Th 8 to 12							
30							12	51
31							14	51
29							35	61

In the group in which scoliosis was accomplished by means of costal resection only the curvature was greater at the beginning than at the end of the observation period in a part of the animals

The level of the costal resection and the number of ribs resected did not have linear influence on the amount of scoliosis Similarly the level of fixation was not in direct correlation to the curvature of the scoliosis

TABLE 3 — *Histological changes in rabbits associated with scoliosis (Explanation of the signs in text)*

Age at the time of operation in days	Post operative time in days	Areas and severity of the histological changes — Fig 18																	
		(1)			(2)			(3)			(4)			(5)			(6)		
		0	I	II	0	I	II	0	I	II	0	I	II	0	I	II	0	I	II
Under 29	0–19	1	2	2	3	1		2	2		3	2		1	5	1	3		
	20–39		2	2	2	2		3	1		2	2			3	1	1	1	
	Over 40			3		1	2		2	2			5		1	2		2	
30–39	0–19	2	3		2	5		4			2	3		2	3		2		
	20–39		3	3	5	1		5	1		4	2		4	2		2	2	
	Over 40		2	5	1	5	1	1	5	1		3	4	1	4		1	3	1
40–49	0–19	4	3	3	3	3	2	5	5		3	5	2	4	5	1	3	2	1
	20–39		2	3	1	3	1	1	4		1	3	1	1	3	1	1	1	1
	Over 40		1	4		3	2	2	3	1		2	3		3	2	2	2	
50–69	0–19	1	1		1	1		1	1		1	1		1	1		1	1	
	20–39	1	1	1	1	1	1		2		2	1		1	2		1	2	
	Over 40			1		1			1				1			1		1	
Over 70	0–19		1			1			1		1			1				1	
	20–39		2			1	1		2		2				2			1	
	Over 40		1	1		2		1	1		2				2		1	1	

changes were also found in older rabbits The changes progress as a function of the post operative time

A casuistic table of the series of rabbits operated upon is presented before the illustrated appendix on page 53 (Table 7)

3 Studies on scoliotic pigs

Development of scoliosis in pigs

The series of pigs operated upon is presented in table 4 The animals were arranged according to the greatest measured scoliotic curvature and according to operative technique

The severest scolioses occurred in the group in which both costal resection and fixation were performed In this group the maximum curvature was almost always attained towards the end of the observation period at worst it was 102°

and the epiphyseal line In this preparation new bone formation stronger than before may be observed on the concave side in both the epiphyses and the diaphyseal area of the vertebra

The development of the structural changes in pig No 18 shown in figures 22 a to c It can be seen from the X ray films that scoliosis has developed rather regularly In the radiogram taken from the preparation distinct structural changes are visible in the apical area Figure 22 d presents a frontal section of the spine Above and below the scoliotic area the vertebral growth is symmetric thus completely resembling the growth of a normal vertebra as previously shown in figure 5 On the other hand there are fairly clear structural changes deviating from the normal in the vertebrae at the apex of the scoliosis the most pronounced being apposition towards the concavity A close up of the apical vertebra is seen in figure 22 e This shows more clearly than before the angle between the present epiphyseal line and the area labelled by tetracycline This indicates that growth has been slower in the epiphyseal line on the concave side The most distinct phenomenon however is apposition towards the concavity A histological slide of the same preparation is seen in figure 22 f Here again the histological changes established previously come to light clearly increased trabeculation in the vertebral diaphysis on the concave side Figure 22 h gives a close up of the epiphyseal line on the concave side It seems to be divided into two parts and the palisade formation of the cartilaginous cells has turned towards the concavity

A series of pictures from pig No 5 is presented in figures 23 a to d The radiogram taken from the preparation showd fairly clear scoliotic changes This pig received two injections of tetracyline the first immediately prior to operation as usual and the second just before killing Figure 23 a presents a cross section of the apical scoliotic vertebra The inner tetracycline line indicates the form of the vertebra at the time of operation The outer tetracycline line bordering on compact bone on the other hand gives its shape immediately prior to killing The area remaining between these two tetracycline lines reveals the additional bone growth after operation It will be seen from the picture that growth towards the concavity has been quite strong While moving towards the convexity on the other hand the tetracycline lines coalesce and the inner line indicating the vertebral structure at the time of operation disappears According to this resorption has occurred on the convex side A histological slide made from this preceding preparation is seen in figure 23 b On the concave side in the area of newly formed bone the compact part is abnormally broad and filled with tiny bone lacunae as shown in close up 23 d There is likewise close up 23 c a dense compact zone on the convex side as is normal A comparison of these two series of pictures shows how clear a picture tetracycline section

gives of the development of deformity The area remaining between the tetracycline lines indicates the site of additional bone growth The conclusion that has been drawn from this is that the trabeculated bone structure, compact bone that is broader than normal and filled with lacunae consists of new bone

The figures presented above are from pigs on whom only costal resection was performed As was shown in the table presented previously, the scoliosis accomplished by costal resection only was in most cases much milder than that effected by means of both costal resection and fixation On the other hand in the vertebrae of the pigs on which fixation was performed new bone formation was less on the concave side These changes are presented numerically in tables 4 and 5

On the other hand in the scolioses effected by costal resection and fixation growth of new bone towards the concavity was remarkably less despite strong radiological alterations An example of this is presented in figures 24 a and b where a scoliosis of 55° had been effected by costal resection and fixation Radiological changes in the vertebrae of the scoliotic area are quite clear On the other hand the structural changes in figure 24 b as demonstrated by tetracycline section are less than was expected It will be noted that in the bone area labelled by tetracycline definite growth of new bone has occurred towards the concavity However the observed growth of additional bone is rather small in extent in comparison with the radiological scoliotic deformity The regularity of this change emerges quite clearly from table 5 The preparation shows that growth in neurocentral epiphyses is somewhat more abundant on the concave side than on the convex side In sections this becomes apparent from the way in which on both sides of the neurocentral epiphysis the distance between the bone areas labelled by tetracycline is definitely longer on the concave side than on the convex side

In figures 25 a and b there is an 84° scoliosis effected by dacron fixation and costal resection A cross section of the apical scoliotic vertebra is presented in figure 25 b Again it will be seen that definite additional bone growth towards the concavity has occurred in the bone area labelled by tetracycline The most distinct change in this preparation however is that growth in the neurocentral epiphysis is definitely stronger on the concavity than on the convex side

A perspicuous view of the quantitative difference in epiphyseal growth between the concave and convex sides is provided by figures 26 and 27 These pairs of tetracycline pictures are of the same preparation as is also the X ray picture The sections were made symmetrically from both sides in the direction of the longitudinal axis of the spine from the centre of the neurocentral epiphysis and perpendicularly towards it

Changes are milder in figures 26 and more severe in figures 27 Both groups of figures however show clearly that on the convex side growth in the end epiphysis is stronger and in the neurocentral epiphysis less than on the concave side

Percentile determination of apposition

The most distinct change observed in the present series was appositional bone growth towards the concavity in the vertebral body These changes were subjected to mathematical analysis Other changes observed included resorption from the convex side asymmetry of the growth in neurocentral epiphysis and retardation of growth in the cranial and caudal epiphyseal lines these changes although regularly observed are not of such a kind that any uniform series of measuring results could be drawn up from them

Of each of the 30 scoliotic pigs one or several photographs in either cros or frontal plane were taken of the apical scoliotic vertebral area Measurement was made from the photographs in the way shown in figure 28 The following measurements were taken of the section thickness = a distance from the tetra cycline line to the edge on the concave side = b distance from the tetracycline line to the edge on the convex side = c. The amount of apposition in per centages was obtained from the formula

$$\text{apposition } \% = \frac{100\,(b-c)}{a}$$

The result of measurement gives only an approximate picture of the amount of apposition Often and especially in the cases of the greatest changes c or distance from the tetracycline line to the edge on the convex side was 0 In these cases such strong resorption had occurred on the side of convexity that the vertebral structure labelled by tetracycline had entirely disappeared from the section In these cases the absolute apposition in percentages is in reality greater than the result of measurement

The results of measurement are shown in table 5 The animals were divided into 4 groups according to operative technique In the table attention wa paid to the following variables age at the time of operation degree of scoliosis observation period and apposition per cent

Tetracycline injection was administered to the animals as already indicated immediately prior to operation Thus the vertebral structure shown by tetracyc line in the section corresponds to the shape at the time of operation As is seen from the table the greatest appositional percentages occurred in pigs subjected to costal resection only The greatest measured apposition per cent is

TABLE 5 — *Percentile apposition towards the concavity in scoliotic pigs*

Operative technique	Pig No	Age at the time of operation in days	Greatest scoliosis	Post-operative time in days	Percentage of apposition
Resection of five ribs	5	56	29	85	15
	7	56	19	85	19
	17	59	53	81	37
	18	59	25	81	32
	13	59	20	104	34
	14	59	9	104	17
	6	66	13	78	6
	8	66	11	78	9
	21	67	21	98	15
	2	74	21	69	16
	1	74	18	69	25
	15	85	13	94	19
	16	83	5	94	12
	10	85	15	51	24
	11	90	25	119	24
	9	93	17	117	25
	4	95	12	84	14
	3	102	16	74	22
Resection of five ribs and fixation	22	55	37	118	6
	23	55	53	82	14
	24	55	18	137	10
	28	56	102	115	19
	27	56	84	115	23
	25	59	50	72	13
	26	59	47	109	12
	19	87	37	111	6
Resection of ribs and hemilaminectomy	20	87	31	111	12
Transection of the ligament	29	43	35	61	28
	31	43	14	51	12
	30	53	12	51	9

37 In this group the scoliotic curvatures are relatively small in comparison with the group where fixation was used In animals upon whom in addition to costal resection fixation was performed high apposition percentages were not observed despite big scoliotic angles However in all the preparations definitely significant apposition towards the concavity was seen In the two last operative groups the apposition changes observed were relatively mild

The amount of the apposition per cent is in relation to the scoliotic curvature. This correlation however is not absolute as can be seen from the table. On the other hand the time interval from operation to the moment of observation (killing) is not in any noteworthy degree in correlation to the amount of apposition per cent. The maximum values of apposition occur in the youngest age group operated upon.

Study of rotation

During the development of scoliosis fairly severe structural changes occur in the vertebrae as has been clearly shown above. If vertebral rotation is studied on the basis of scoliotic preparations the result obtained is not correct because quite strong remodelling changes occur in the vertebrae following scoliosis-provoking operation. In the present study rotation in scoliotic pig vertebrae was determined according to the vertebral structure at the moment of operation. This was made possible by utilizing the tetracycline-labelled vertebral area which depicts the vertebral structure at the moment of operation. Two methods were employed in rotational studies. The methods are presented schematically in figure 29.

In the first method tetracycline was injected into the animal in the usual way immediately prior to operation. Following scoliosis-provoking operation the animals were killed after a certain period. The vertebrae of the scoliotic area bordering both cranially and caudally on neutral areas were sawn off in the cross plane. Each cross-section surface was photographed in the normal way in ultraviolet light. This gave a series of preparations an example of which is seen in figure 30. Next, tracks were drilled at the sites of the tetracycline lines identified by means of ultraviolet light and so illustrated the vertebral structure at time of operation. A flexible wire was implanted in these tracks

TABLE 6 — *Rotation in a scoliotic spine*

Pig No	Measuring technique	Scoliosis in degrees	Scoliotic area Th No Th No	Number of intervertebral spaces	Rotation in degrees	Rotation per intervertebral space
21	I	21	8–12	4	10	3.0
2[illegible]	II	[illegible]0	5–1[illegible]	8	25	3.[illegible]
[illegible]	I	19	8–12	4	–	3.5
9	II	1[illegible]	6–11	5	6	2.5
25	II	[illegible]	[illegible]–13	6	20	6.5
20	II	51	[illegible]–12	5	10	4.0

Similarly the sites of neurocentral epiphyses were marked by wires in each cross cut surface The vertebrae were then replaced in their former sites on top of each other and radiograms were taken in the cranio caudal direction X raying was then continued the topmost vertebra being removed each time until the last one was X rayed alone In this way it was possible to identify each vertebra separately Enlargements of the radiograms were prepared on photo graphic paper Measurement of rotation was performed according to figure 29 a in regard to the bone structure labelled by tetracycline and represented in the radiogram by the implanted wires The line drawn runs against the vertebral body at the moment of operation in places of neurocentral epiphyses at that time Thus it was possible to calculate rotation in the entire scoliotic area as well as the rotation of individual vertebrae in relation to the vertebral structure at the moment of operation

In the second method which is diagrammatically presented in figure 29 b, the scoliosis provoking operation and tetracycline injections were performed in the ordinary way By means of a radiogram taken of the preparation the neutral vertebrae i e those with no rotation or vertebral asymmetry, were identified in both the upper and lower ends of scoliosis The preparation was cut off from above and below the neutral vertebrae A hole for the leading wire was drilled through the middle of the neutral vertebrae in a sagittal direction The apical scoliotic vertebra was identified from both the radiogram and the preparation The sites of the neurocentral epiphyses were identified laterally in ultraviolet light A leading wire was implanted through them in the frontal plane A radiogram was taken of the preparation with the leading wires in the cranio-caudal direction so that the leading wires placed in the neutral vertebrae were in the same plane The apical vertebra was sawn off at the level of the leading wire implanted in cross plane The cross-cut surface where the site of the leading wire could be clearly identified was photographed in ultraviolet light In place of the leading wire implanted through the apical vertebra in the radiogram a line was drawn according to a picture taken of the tetracycline preparation this line ran in relation to the tetracycline labelled area as is shown in figure 29 b From this line and the sites of the leading wires placed in the neutral vertebrae it was thus possible to calculate the degree of rotation in degrees in the area of scoliosis

By means of the methods described rotation was studied in 6 pigs The aim of the study was not to establish exactly the amount of rotation in regard to the scoliotic curvature Since the tetracycline method has made it possible to study rotation in regard to the vertebral structure at the time of operation the aim of the present study was to try to find out whether *rotation is a real change between various vertebrae* or whether the changes are merely a consequence

of the remodelling of the bone during the development of scoliosis The rotational changes are shown in table 6 Two pigs were studied by the first method and four by the second method These different methods were considered to yield uniform results although the second method is technically easier The amount of rotation is given in degrees from the neutral vertebra to the apical vertebra The amount of rotation for each two adjacent vertebrae is obtained directly in the first method and in the second by dividing the total rotation by the corresponding number of intervertebral spaces As can be seen from table 6 rotation occurred even in milder scolioses its amount growing as the scoliotic curvature increased However as the table shows there is no direct linear correlation between scoliotic curvature and degree of rotation Fairly definite rotation was found even in the smallest scoliosis of 17° Nevertheless even in the greatest 53° rotation between any two vertebrae did not rise higher than 6 8°

The present study has shown that in scoliotic spine rotation occurs between various vertebrae This observation supports earlier findings The amount of rotation is found to grow as the scoliotic curvature increases – but the correlation is not linear

Alterations in spinous process

In the pig the spinous processes point almost directly dorsally only in the middle parts of the thoracic spine On the other hand in the cranial part of the spine they deviate to caudal and correspondingly in the caudal part to cranial directions The study was therefore limited to the middle part of the thoracic spine It is true of course that the scoliotic changes effected in the experiments were as a rule located in this area

The spinous process normally grows perpendicularly in a dorsal direction The tetracycline method shows that the spinous process labelled by tetracycline is situated symmetrically inside the spinous process that had grown after the injection (Fig 31 a)

Scoliotic spinous processes were examined in 16 pigs Changes were studied in the middle of the thoracic spine which as was mentioned before forms the apical region of scoliotic changes The changes observed in various preparations are mainly similar

Figure 31 b shows the spinous process of pig No 19 A scoliosis of 37° had been accomplished in this pig As is seen from the picture the area labelled by tetracycline which thus depicts the position of the spinous process at the moment of operation is pointing directly dorsally On the other hand during the postoperative period as the scoliotic deformity progressed the spinous process clearly grew towards the concavity

In the same way figure 31 c illustrates pig No 26 whose scoliosis was 47° The changes described above are still more clearly visible in this preparation The tetracycline labelled spinous process is hardly visible at all so strong has been the drift towards the concavity Because of the diffuse nature of the changes no measurements were taken

V DISCUSSION

Previously when scoliotic structural changes were studied it was generally concluded that structural changes are consequences of passive deformation. In the present study it has emerged that although changes caused by passive deformation do exist structural changes are also influenced by the process of growth that compensates lateral deviation.

In order to obtain an adequate basis for studies on scoliosis normal vertebral growth was also investigated.

Because it is safe and easy to use tetracycline labelling has provided good facilities for following the structural changes caused by both normal growth and scoliosis despite their rapid development.

The use of tetracycline is based on its property of becoming incorporated in newly formed bone. While it is true that in other investigations tetracycline has also been found to find its way to tissues undergoing necrobiotic changes such changes did not occur in the area of scoliotic spine involved in this study.

In bone studies the tetracycline method has proved as certain and reliable as the use of isotopes (Kelly et al.). The bone structure that becomes visible in ultraviolet light shows the form of the bone at the moment of injection. Thus it may be concluded that if the tetracycline line has disappeared from some area resorption has occurred in that particular place and in the same way if in relation to the tetracycline line bone without tetracycline is observed, it has grown after the injection.

The animals operated on in the present study were given injections of tetracycline immediately before operation. The changes that occurred in the area so labelled were postoperative. From them it has been possible to follow the development of scoliotic structural changes and to analyze them.

It was found that rabbit and pig vertebrae like human vertebrae grow in the same way as long bones. Growth from the cranial and caudal end epiphyses is symmetric although the view has sometimes been presented that the cranial zone of growth possesses a better capacity for proliferation (Moser Muller). Growth in lateral directions is symmetric apposition. The epiphyseal plates at the ends of rabbit and pig vertebrae do not grow in the cranio-caudal direction

to any extent worth mentioning Lateral growth occurs in relation to other vertebral growth (Fig 5)

Comparatively little attention has previously been paid in the literature to the growth of the neural canal The neurocentral epiphysis previously found in human vertebrae has also been observed in rabbits and pigs It also grows in two directions This was verified in the present study by means of the tetra cycline method

The neurocentral epiphysis has already been found to be definitely involved in the growth of the neural canal (*Knutsson*) In the present study it was revealed that growth occurs in different ways depending on whether the neurocentral epiphysis is closed or not.

In the neurocentral epiphysis maturation and growth of the cells do not always occur perpendicularly towards the epiphysis concerned While the *neurocentral epiphysis is open the neural canal expands through the growth of* this epiphysis and also through resorption and apposition activities in a dorsal direction After closure of this epiphysis the neural canal expands symmetrically (Figs 6 and 7)

Along with the growth of neurocentral epiphysis formation of new bone has been found in dorsal parts of the vertebral body (Fig 5) The dorsal part of the vertebral body is the imaginary point which as stated earlier by *Ponlot*, is the centre of vertebral growth

Scoliosis was effected in laboratory animals by operating on the right of the central part of the thoracic spine because scoliosis in man is usually convex to the right and located in the area of the thoracic spine (*Moe Shands* and *Eis berg*) Costal resection has been found to be a sure procedure for provoking coliosis (*Langenskiold* and *Michelsson*) In the present study the main emphasis was not put on the question as to what surgical procedure would produce which amount of scoliosis the aim was to produce various degrees of coliosis *and to study the development of structural changes in them* as a func tion of post operative time and scoliotic curvature

Histological changes found in rabbits were dealt with in greater detail as there was abundant material and observations were systematically timed The results are shown in tables 3 and 7 In previous literature scoliotic structural changes have been described *in great detail* but *larger series in* which the nature of these changes could have been elucidated do not exist

In dealing with scoliotic structural changes attention has been paid to the areas indicated in figure 18 So called trabeculated structure was regularly found in the areas of vertebral bodies and arches This bone structure is compact bone that is thicker than usual and contains more than the normal number of lacunae On the basis of observations made simultaneously with

tetracycline study this bone structure may be considered as new bone that has developed since the scoliosis provoking operation (Fig 25)

Even very early only 5 days after operation structural changes were found (Fig 8) These changes become distinctly more severe as a function of post operative time Moreover the greatest changes were found in the greatest scoliotic curvatures The changes first appear on the concave side of the vertebral body and later in other areas (Table 3) Changes typical of scoliosis could also be accomplished in older rabbits who were however still growing Scoliotic structural changes are greatest at the site of the apical vertebra and decrease gradually towards the neutral area (Fig 14)

The role of the neurocentral epiphysis has been surveyed in the literature where it has been mentioned as an etiological factor in the development of scoliosis (*Roaf*) However it was found in the present study that almost as a rule the growth of neurocentral epiphysis is disturbed on the convex side this being therefore a secondary structural change associated with scoliosis caused by a paraspinal procedure

In previous studies most attention has been paid to histological changes in the end epiphyses The conclusion has been reached that on the concave or pressure side the epiphyseal cartilaginous cells are irregularly situated the cartilaginous pillars are deformed and chondrocyte proliferation is decreased Similar changes were also seen in the present study It was further observed however that the epiphyseal line is in some preparations thicker on the concave side although irregular It was found that the cartilaginous cells had definitely increased in number and had begun to grow towards the concavity (Figs 17 c and 22 h)

In tetracycline studies performed on pigs it was found in numerous preparations that the growth in neurocentral epiphyses is strongest on the concave side that is under pressure On the other hand it clearly emerged that growth in the end epiphyses is retarded in this area The quantitative difference in the growth of these epiphyses situated at different levels is most distinctly apparent in figures 26 and 27 While the above mentioned changes in scoliotic pig vertebrae are clear the most conspicuous change in all the preparations examined was strong appositional growth towards the concavity (Figs 19 to 25 and 30)

As has been mentioned in several studies rotation is an essential factor in scoliotic deformities The degree of rotation has been determined by examining vertebrae deformed by scoliosis In clinical studies the degree of rotation has sometimes been determined from the top of the spinous process (*Casagrande and Frost*) However by using the tetracycline method it has been possible to establish that when the scoliotic deformity progresses the spinous process is drift

ed towards the concavity (Fig 31) The cause of this apparently is a state of tension between interspinous ligaments and other soft tissues Because of deformation of the spinous processes the estimation of the site of the spinous process apex does not give a correct view of the amount of rotation but greater than normal values are obtained

In the present study the rotation of the scoliotic vertebrae was determined in regard to the vertebral structure at the moment of operation Post operative remodelling changes associated with scoliosis were thus eliminated and the true rotation could be observed Rotation to a maximum of 6 8° per any two adjacent vertebrae was observed in all 6 of the preparations examined (Table 6) The rotation was found to increase as the scoliosis progressed although there is no linear correlation between scoliotic curvature and degree of rotation

Many of the remodelling changes observed seemingly influence rotation These include apposition towards the concavity and differences in growth between the neurocentral epiphyses (Fig 29) Apposition towards the concavity apparently diminishes rotation On the other hand the stronger growth of the neurocentral epiphysis on the concave side seemingly increases it

In the tables illustrating the development of scoliosis it was found as was mentioned above that the scolioses accomplished in rabbits almost regularly progressed as a function of post operative time On the other hand some of the pig scolioses became somewhat straighter later on This was particularly apparent in scolioses resulting from costal resection only A probable cause of this could be the scars formed on the operative area i e on the concave side because such scars have been found to interfere with scoliosis (*Langenskiold* and *Michelsson*) On the other hand the operation was obviously a greater trauma to rabbits than to pigs

The greatest appositional changes were observed in those groups in which only costal resection had been performed On the other hand in the group in which fixation on the concave side was also carried out the apposition percentages were clearly lower This might be explained by the fact that in the group of fixed spines the scoliosis inducing stretching force which grows continuously worse as the spine grows is so severe that it would not have been possible for reparative changes to effect the straightening analyzed in the following pages

As was mentioned in the histological discussion it was possible after the scoliosis provoking operation to observe changes on the concave side of the vertebrae which might be interpreted as new bone The same change is clearly visible in table 5 which gives the amount of apposition in percentages in pigs Changes were found in all the test animals which indicate that there is stronger growth towards the concavity in the vertebral bodies From the histological

changes observed in the area of the neural canal, i.e. trabeculation on the convex side, it is possible to draw the conclusion that the entire neural canal has a tendency to drift towards the concavity.

The generally accepted opinion has been that the wedged vertebra is a consequence of passive deformation according to the *Hueter-Volkmann* law (Fig. 32), whereby increased pressure on the concave side would result in retardation of growth in the epiphyseal line of this area. These changes were also observed in the present study (Figs. 16c, 21c and 22c), although their part in forming the wedged vertebra is relatively small. A concept deviating from this was presented by *Maass* in 1902 (Fig. 33). According to him quantitative growth undergoes no changes through the effect of pressure but occurs in the direction that is free from pressure, towards the concavity.

This study does not completely corroborate the theory of *Maass* because the retardation of growth observed in the end epiphyses does not quantitatively cover the amount of lateral apposition. Nor is the amount of apposition irrefutably explained by the periosteal stretching theory of *Stilwell*.

It is a generally known fact that pressure increases bone growth. A good example of this is seen in figure 37 which shows the tendency towards straightening in fractures that have healed at an angle. At the site of angulation there is apposition on the concave and resorption on the convex side. There is therefore a drift towards the concavity in this bone.

The present study is also an example of the validity of *Wolff*'s law. The spine, although composed of several vertebrae, is a functional unit which has a clear tendency to find its way to the midline.

The final result of the present study is shown by the diagram in figure 39.

In this study on rabbits and pigs with experimental scoliosis the conclusion was reached that the structural changes caused by scoliosis are not exclusively the results of passive deformation but among the factors underlying the changes there is also a growth process that tries to counterbalance lateral deviation.

VI SUMMARY

The aim of the experimental study was to elucidate the structural changes occurring in scoliosis and to scrutinize normal growth of the vertebra

The study was performed by using rabbits and pigs as test animals There were 121 rabbits and a scoliosis provoking operation was performed on 78 of them The number of pigs was 47 30 of which were operated on (Table 1) 51 rabbits and 15 pigs served as control material

Roentgenograms and the tetracycline labelling method were used Histological preparations were also made of the sections (Table 1)

A scoliosis provoking operation was performed on the rabbits by resecting 5 ribs dorsally on the right side In the pigs scoliosis was induced by four different methods 1 by resecting 5 to 8 ribs dorsally on the right side 2 by resecting 5 to 8 ribs dorsally on the right and by performing dacron thread fixation on the left side 3 by severing the ligaments attached to the dorsal end of the rib and 4 by resecting 5 ribs from the right side and by also performing hemilaminectomy on the same level (Table 4) The most severe scolioses were attained in the pigs by means of costal resection associated with fixation (Table 4)

The rabbit and pig vertebrae were found to grow to equal extents in both end epiphyses while apposition was symmetrical laterally (Figs 1 to 5) Growth of the neural canal was found to be different depending on whether the neurocentral epiphysis was closed or not (Figs 6 to 7)

In histological examination of scoliotic vertebrae additional bone growth was found on the concave side as well as in the medial part of convexity in the neural canal The growth of the neurocentral epiphysis was found to be disturbed on the convex side almost uniformly as scoliosis developed In the end epiphyses irregularities of the cartilaginous cells were observed on the concave side (Tables 5 and 7 Figs 8 to 17) On the other hand the end epiphysis was often thickened on the concave side and the direction of maturation of the cartilaginous cells had turned towards the concavity (Figs 17 c and 22 g)

By means of the tetracycline method definite apposition towards the concavity was found in all examined scoliotic pig preparations (Figs 19 to 25 and 30) The amount of apposition was measured percentually and was found to

be largest in animals with only costal resection (Table 5 Fig 28) Althoug addit ional fixation resulted in the greatest deformities the percentile amounts of apposition were smaller The neurocentral epiphysis was found to grow more strongly on the concave than on the convex side (Figs 25 to 27)

A study was performed in six pigs in order to unravel the actual rotation in relation to the vertebral structure at the time of operation with the tetracycline method *Distinct rotation was found in all and it increased* although not linearly as the scoliotic curvature increased (Table 6 Figs 29 and 30) The spinous process was found to have turned towards the concavity as a result of apposition and resorption (Fig 31)

In this study on rabbits and pigs with experimental scoliosis the conclusion was reached that the structural changes caused by scoliosis are not exclusively the results of passive deformation but among the factors underlying the changes there is also a growth process that tries to counterbalance lateral deviation

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TABLE 7 – *Changes found in rabbits*

Rabbit No	Age at the time of operation in days					Post-operative follow-up period				Scoliosis in degrees			Histological changes
	Under 29	30—39	40—49	50—59	Over 60	0—19	20—39	40—69	Over 70	0—29	30—59	Over 60	
1		+						+		+			
3	+							+			+		
5				+			+			+			0
9			+						+			+	II
10	+								+	+			II
11	+								+		+		II
12			+					+				+	II
13	+								+			+	II
14			+			+					+		0
15		+				+					+		I
16		+					+			+			I
17		+				+					+		0
18	+							+				+	
19		+				+					+		0
20		+					+				+		II
21		+					+				+		I
22		+				+					+		I
24		+				+					+		I
25		+					+					+	II
26		+					+				+		I
28		+					+				+		II
31		+						+				+	II
32					+		+				+		I
33			+					+				+	
34			+					+			+		
35			+					+				+	
36			+			+					+		II
37			+				+			+			I
38			+				+				+		I
39			+			+					+		I
41			+				+				+		II
42	+					+						+	I
43	+					+					+		I
44	+					+						+	I
45	+						+				+		I
47				+		+					+		I
48					+		+				+		I
49				+			+					+	II
50				+		+					+		0
59				+					+			+	II
60	+						+					+	
61	+							+			+		
62		+						+			+		
63			+				+			+			II
64					+	+				+			I
65				+			+					+	I
68					+				+			+	II
70					+				+			+	II
75			+			+					+		II
76			+			+						+	I
77			+					+			+		II
78			+					+				+	II
79			+				+					+	II
80			+						+		+		II
81			+					+				+	II
82					+				+			+	
83	+							+			+		II
85	+					+						+	II
88			+			+				+			0
89			+			+				+			0
90			+			+						+	II
92			+			+					+		
93	+						+			+			I
94			+						+		+		
95		+						+			+		I
96		+						+				+	II
97		+					+					+	II
98		+					+					+	II
99	+								+			+	
101	+								+			+	
104			+			+				+			0
107			+			+						+	II
108	+						+					+	II
109		+							+			+	
111	+								+		+		
112		+						+				+	II
116		+						+				+	II
117	+					+				+			II
Total	19	21	26	6	6	24	22	18	14	12	33	33	

0 = Nothing I = Slight [illegible]ver

1 b

FIG 1 a and b — a *Frontal section of a normal vertebra (th 7) 60 day-old rabbit Epiphyseal plates cranially and caudally separated from diaphysis by epiphyseal line* — b Magnification of epiphyseal area Epiphysis is formed by cartilaginous cells maturing *in one direction*



FIG 2 a and b — a Frontal section of a normal vertebra (th 6) 92 day-old pig *Epiphyseal plates cranially and caudally separated from diaphysis by epiphyseal line* — b *Magnification of epiphyseal line Epiphysis is formed by cartilaginous cells maturing in one direction*



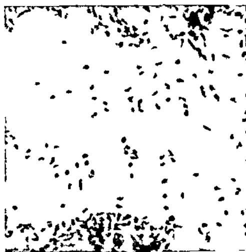


FIG 3a and b — a *Cross section of a normal vertebra (th 6) 52 day old rabbit Compact bone laterally and around neural canal Between them loose spongiosa In the border between corpus and arcus symmetric neurocentral epiphyses on both sides* — b *Magnification of the neurocentral epiphysis Epiphysis consists of cartilaginous cells maturing in two directions*

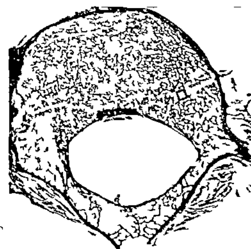
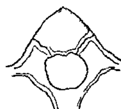




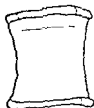
FIG 4a and b — a *Cross section of normal vertebra (th 6) 87 day old pig Compact bone laterally and in the area of neural canal between them dense spongiosa Neurocentral epiphyses symmetrically in the border between corpus and arcus* — b *Magnification of the epiphyseal area shown in fig 4a Epiphysis consists of cartilaginous cells maturing in two directions*





a



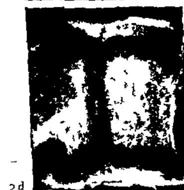


b





c





d

FIG 5a–d Normal pig *The animal was killed at the age of 160 days The sections were photographed in ultraviolet light The area labelled by tetracycline illustrates the form of the vertebra at the time of injection In the diagrams the area labelled by tetracycline is shown by the blue line* — a Cross *section Growth in lateral direction is symmetric Symmetric growth from neurocentral epiphysis towards both the body and arch Apposition in dorsal part of the body* — b *Frontal section Symmetric apposition towards lateral direction in the areas of both diaphysis and epiphysis* — c *Sagittal section* Equal amount of growth from both the cranial and *caudal epiphyses Apposition ventrally and dorsally* — d *Figure shows growth from neurocentral epiphysis*



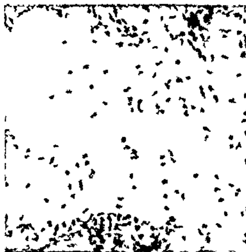


FIG. 3a and b — a. *Cross section of a normal vertebra (th 6) 52 day-old rabbit. Compact bone laterally and around neural canal. Between them loose spongiosa. In the border between corpus and arcus symmetric neurocentral epiphyses on both sides.* — b. *Magnification of the neurocentral epiphysis. Epiphysis consists of cartilaginous cells maturing in two directions.*

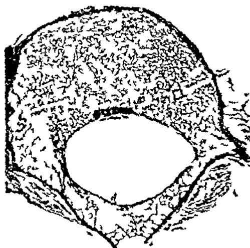




FIG. 4a and b — a. *Cross section of normal vertebra (th 6) 87 day-old pig. Compact bone laterally and in the area of neural canal, between them dense spongiosa. Neurocentral epiphyses symmetrically in the border between corpus and arcus.* — b. *Magnification of the epiphyseal area shown in fig. 4a. Epiphysis consists of cartilaginous cells maturing in two directions.*

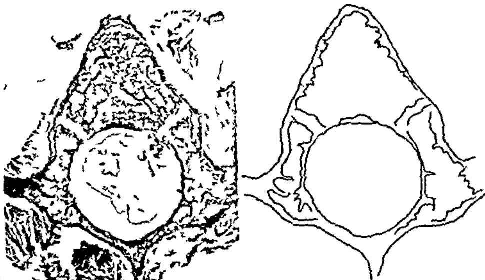


FIG 8 *Rabbit No 41 was operated upon at the age of 28 days and killed 5 days later* Scoliotic curvature 41° Cross section *of the apical scoliotic area Bone structure somewhat thickened on the concave side*



FIG 9 *Rabbit No 42 was operated upon at the age of 22 days and killed 11 days post operatively* Scoliotic curvature 61° *Cross section of the apical scoliotic area Increased trabeculation on the concave side Neurocentral epiphysis is broader on the concave than on the convex side*



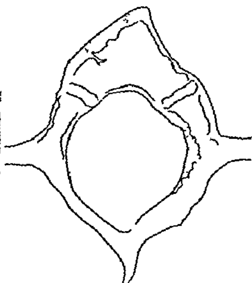


FIG 10 *Rabbit No 39 was operated upon at the age of 43 days killed 18 days post operatively Scoliotic curvature 35° Increased trabeculation on the concave side Neuro central epiphysis broader on the concave side Arch symmetric Trabeculation increased in the medial part of arch on the convex side*



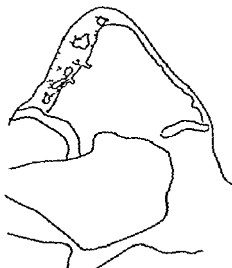


FIG 11 *Rabbit N [illegible] perated upon at the age of 45 days and killed 51 days post operatively Scoli [illegible] ature [illegible] ° Strongly increased trabeculation on the concave side of the body N[illegible] ent [illegible] epiphysis g eatly narrowed n the convex side*



FIG 12 *Rabbit No 98 was operated upon at the age of 38 days killed 38 days later Scoliotic curvature 78° Trabeculation greatly increased on the concave side Neurocentral epiphyses on both sides completely ossified Neural canal asymmetric*



FIG 13 *Rabbit No 69 was operated upon at the age of 76 days and killed 90 days postoperatively Scoliotic curvature 95° Trabeculation increased on the concave side Neurocentral epiphyses closed*



14 a

FIG 14 a – f *Rabbit No 112 was operated upon at the age of 35 days and killed 51 days thereafter Scoliotic curvature 98°* – a *X ray immediately before killing Vertebrae of the apical area severely deformed* – b *Th 6 Neurocentral epiphysis partly ossified on the convex side Increased trabeculation on the concave side of corpus* – c *Th 7 Trabeculation clearly increased on the concave side and in the medial part of the arch on the convex side Neural canal deformed Neurocentral epiphyses closed on both sides* – d *Th 8 Changes similar to those in figure* c – e *Th 9 Increased trabeculation on the concave side and in the medial part of the arch on the convex side Neurocentral epiphysis completely ossified on the convex partly open on the concave side* – f *Th 10 Almost normal bone structure Neurocentral epiphysis somewhat broader on the concave than on the convex side*





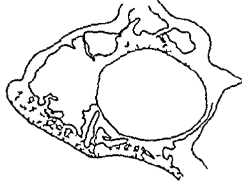
14 b

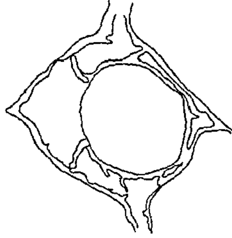




14 c

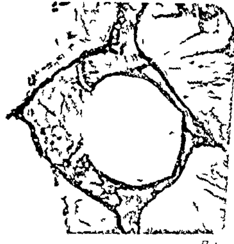














4 a

FIG 14 a – f *Rabbit No 112 was operated upon at the age of 35 days and killed 51 days thereafter Scoliotic curvature 95°* – a *X ray immediately before killing Vertebrae of the apical area severely deformed* – b *Th 6 Neurocentral epiphysis partly ossified on the convex side Increased trabeculation on the concave side of corpus* – c *Th 7 Trabeculation clearly increased on the concave side and in the medial part of the arch on the convex side Neural canal deformed Neurocentral epiphyses closed on both sides* – d *Th 8 Changes similar to those in figure* c – e *Th 9 Increased trabeculation on the concave side and in the medial part of the arch on the convex side Neurocentral epiphysis completely ossified on the convex partly open on the concave side* – f *Th 10 Almost normal bone structure Neurocentral epiphysis somewhat broader on the concave than on the convex side*

4 b



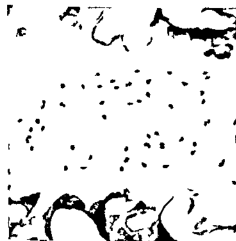
14 c





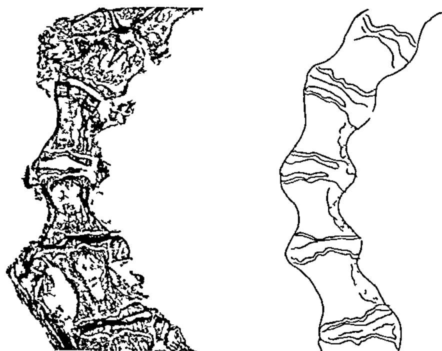

e




g




15 i



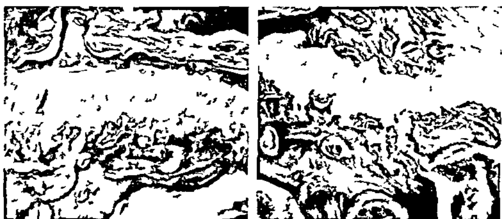


FIG. 16 a—c. *Rabbit No. 96 was operated upon at the age of 31 days and killed 41 days post-operatively. Scoliotic curvature 62°.* — a. *Frontal section. Vertebrae severely wedge formed and the nuclei pulposi have moved towards the convexity. Increased trabeculation on the concave side.* — b. *Magnification of the epiphyseal area on the convex side. Cartilaginous structure normal, palisades regular.* — c. *Magnification of the epiphyseal area on the concave side. Cartilaginous cells are unequally distributed. Cartilaginous layer is lowered and normal palisade formation disturbed.*

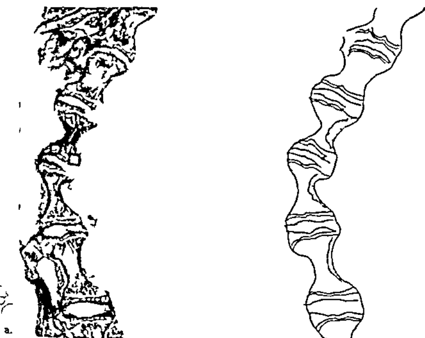




FIG 17 a – c *Rabbit No 75 was operated upon at the age of 48 days and killed 18 days post operatively* – a *Scoliotic curvature 58°* – b *Magnification of the epiphyseal area on the convex side Cartilaginous structure normal* – c *Magnification of the concave side Cartilaginous layer is wider than normal and irregular*

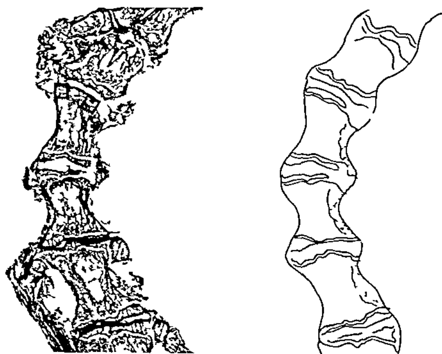






FIG 16 a – c *Ral bit No 9(uas operated upon at the age of 31 days and killed 41 days post operatiu ely Scoliotic curi ature 62°* — a *Frontal section Vertebrae seterely uedge formed and th nuclei pulposi hate moted touards the conexity Increased trabeculation on the ncai e side* — b *Magnification of the epiphyseal area on the conex side Cartil u structure normal palisades regular* — c *Magnification of the epiphyseal area concai e side Cartilaginous cells are unequally distributed Cartilaginous layer 1 and normal palisade formation disturbed*









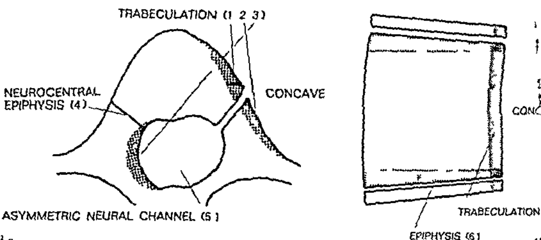


FIG 18 a and b *Diagrams of histological changes observed in scoliotic vertebrae — a Cross section — b Frontal section Explanations in the text*



FIG 19 a – c *Pig No 4 The right ribs 7–11 were resected at the age of 91 days Ten days post operatively the scoliotic curvature was 12° The animal was killed 84 days post-operatively when the scoliotic curvature was 5° — a X ray of the preparation with no noteworthy structural alterations — b Frontal section of apical area of scoliosis Tetracycline injection was administered immediately before operation Growth from cranial and caudal epiphyseal plates is symmetric Definite apposition 14 % on the concave side The tetracycline line has disappeared on the convex side showing resorption in this area — c Cross section Growth from neurocentral epiphysis occurs symmetrically Definite apposition towards the concavity*







continued

22 e Close up of the apical vertebra There is a definite apposition of 32 ° toward the concavity Both the cranial and caudal epiphyseal lines form an angle with the tetracycline line This shows retardation of growth in both end epiphyses on the concave side — f Histological section of the specimen in e Increased trabeculation is seen on the concave side of the diaphysis — g Epiphysis on the convex side is normal — h Magnification of the concave side epiphyseal area The epiphysis is wid r than normal An in reased numb er of cartil aginous cells also on the cranial sid of the epiphysis The direction of maturation of the cartilaginous cells has turned towards the concavity

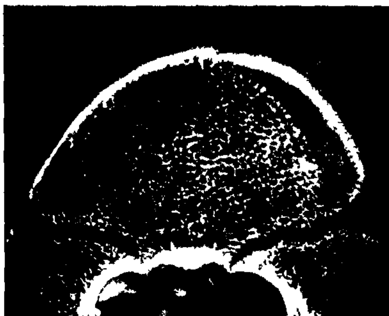




FIG 25 a – d *Pig No 5 was operated upon at the age of 56 days and killed 83 days post operatively The scoliotic curvature is 29° and percentile apposition 15 % The pig received two injections of tetracycline one prior to operation and the other immediately before killing* – a *Cross section of the apical vertebra The inner tetracycline line illustrates the form of the vertebra at the moment of operation and the outer one just before killing Between the tetracycline lines on the concave side there remains an area which illustrates the additional bone growth since the operation* – b *Histological preparation of a* – c *Magnification of the convex side part of the vertebral body with normal bone structure* – d *Magnification of the concave side part of the body where the bone structure is trabeculated*







25 d



a

FIG 24 a and b Pig No 21 The right ribs 8–12 were resected at the age of 55 days and the levels th 6–8 and th 13–[illegible] were fixed with deflon thread on the left Scoliotic curvature 51° The animal was killed 82 days post-operatively — a X-ray shows strongly deformed vertebrae in the scoliotic area — b Tetracycline section of the apical scoliotic area in cross plane Tetracycline injection was administered immediately prior to the operation There is apposition towards the concavity both in the body and arch 14 × Growth from the neurocentral epiphysis is somewhat greater on the concave side



b





FIG 25 a and b *Pig No 27 The right ribs 8–12 were resected at the age of 56 days and deflon fixation was performed to the left on areas th 6–9 and th 13–6 The pig was killed 115 days post operatively* — a *Scoliotic curvature 84° Vertebrae in the scoliotic area are severely deformed* — b *Cross section from the apical area of figure a There is definite apposition towards the concavity both in the body and arch 23 % In the neurocentral epiphysis growth is clearly stronger on the concave than on the convex side*





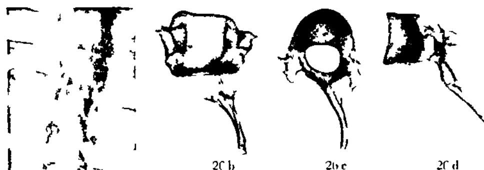
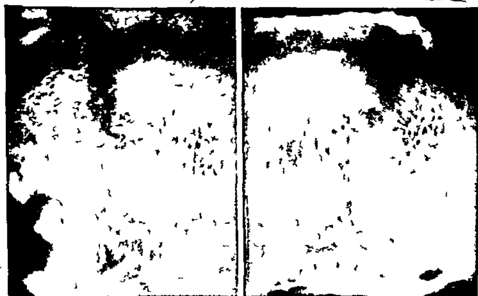


FIG. 26 a – f. Pig No. 13 was operated upon at the age of 59 days prior to which tetracycline injections were administered. – a. X-ray of the preparation whose scoliotic curvature is 1[illegible]°. – b–d. X-rays of the apical vertebra. – e. Tetracycline section from the convex side. – f. Same section from the concave side. On the convex side growth is stronger in the end epiphyses and less in the neurocentral epiphyses than on the concave side.

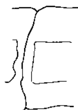






a

FIG 27 a – c *Pig No 24 Scoliosis provoking operation was performed at the age of 55 days* — a *X ray of the preparation Scoliotic curvature is 45° Tetracycline sections were taken as figure 26* — b *from the convex and* — c *from the concave side On the concave side growth has been greater in the neurocentral epiphyses and less in the end epiphyses*







b



27 c

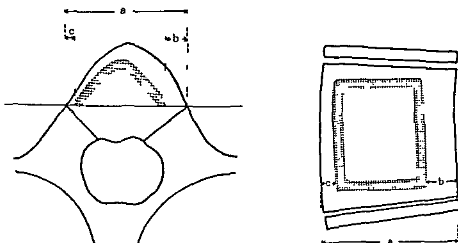


FIG 28 a and b *Diagram of the principle according to which the percentile apposition was measured* a *is thickness of the vertebral body at frontal level* b *is amount of newly formed bone from the tetracycline labelled area towards the concavity* c *is amount of newly formed bone on the convex side*

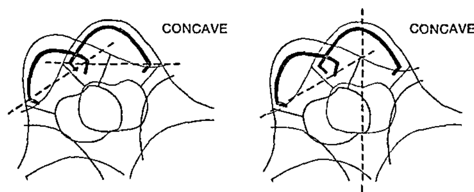


FIG 29 a and b *Diagram of methods of study for determination of the real rotation The neutral vertebra is denoted in black the apical scoliotic vertebra in red The blue area is that labelled by tetracycline and illustrates the shape of the vertebra at the moment of operation* — a *Method I Broken line shows the axes according to which the rotation was determined* — b *Method II Broken line shows the location of direction pins in the neutral and apical vertebrae Fuller explanation of the methods is given in the text*

FIG 30 a



b


c


d


e


f


FIG 30 b–f



30 b



30 c



30 d



30 e



30 f

31 b 31

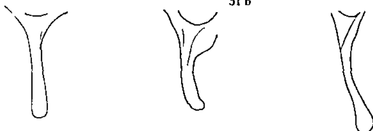


FIG 31 a – c *Turning of spinous process towards the concavity in tetracycline sections* – a *Normal situation Tetracycline occurs symmetrically in the center of the area* – b *Slight turning of spinous process towards the concavity* – c *Spinous process is deviating strongly towards the concavity The area labelled by tetracycline is hardly visible*

FIG 30 a – f *Pig No 1 The right ribs 8–13 were resected at the age of 47 days The animal was killed 98 days following resection Tetracycline was injected immediately before operation* – a *Scoliotic curvature in the specimen 21° Definite rotation is seen in the vertebrae of the scoliotic area Some wedge deformation in the vertebrae Cross sections at various levels of the preparation shown in the figure a In figure* b *and* f *showing upper and lower neutral vertebrae the growth is symmetric On the other hand definite apposition towards the concavity is seen in the three apical vertebrae greatest in the section d*

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An autoradiographic study with ^{35}S-sulphate on the growth in diameter of epiphyseal cartilage in rabbits

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From the Orthopaedic Hospital of the Invalid Foundation
Helsinki Finland (Head Professor A Langenskiöld M D)

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INTRODUCTION

There is no unanimity of opinion in the literature regarding the manner in which the epiphyseal cartilage grows in diameter. It seems to be a wide-spread opinion that the diametric growth of the epiphyseal plate takes place by apposition of cells from a perichondrium on the peripheral surface and above all from the border zone between the cartilage and the diaphyseal periosteum, the so-called »ossification groove« of Ranvier. This opinion has been put forward by Kollath and Lacroix among others. The contrary opinion that the cells of the »ossification groove« derive their origin from the epiphyseal cartilage and that the latter grows in diameter by interstitial growth was adopted by several classic authors (Ranvier, Policard, Carey, Dahl).

Recent experiments presented in support of the view that the diametric growth of the epiphyseal plate occurs by apposition of cells from the periphery include those of Tonna (1961) and Tonna & Cronkite (1963). In the light of autoradiographic studies in mice with ^{3}H thymidine, the conclusion was reached that the periosteum acts as a chondro-osteogenic progenitor cell pool by supplying cells for the expansion of the epiphyseal cartilage. Rigal (1962), however, arrived at the contrary opinion on the basis of his extensive studies with rats and rabbits employing cell labelling with ^{3}H thymidine both *in vivo* and *in vitro*. His conclusion was that endochondral proliferation of cells was responsible for the diametric growth of the epiphyseal cartilage.

Other approaches to the problem have been made in many ways and by many authors, but opinions have remained divided. For instance Friedenberg (1956, 1957) resected a part of the epiphyseal plate surgically and interpreted the narrowed transverse diameter of the newly formed bone as an indication against the idea of enchondral growth. Leblond & Greulich (1956) suggested that transformation of fibroblasts into chondrocytes takes place in the periphery of the epiphyseal cartilage and that this apposition is responsible for the diametric growth of the epiphyseal plate.

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much weaker reaction. The initial labelling is most intense in the cells of the growth zone of the epiphyseal cartilage (BELANGER 1956, ENGFELDT & WESTERBORN 1960, DZIEWIATKOWSKI 1962b).

It has been well demonstrated that cartilage is permeable to inorganic sulphate both *in vivo* and *in vitro* (CAMPO & DZIEWIATKOWSKI 1961). Almost as rapidly as sulphate enters the tissue the inorganic ion is utilized by the cells in the synthesis of chondroitin sulphate (DZIEWIATKOWSKI 1962a). After 4 hours labelling *in vitro* only about 15 % of the radioactivity is seen in the matrix, on the other hand 64 to 83 % of the total ^{35}S could be isolated as chondroitin sulphate (DZIEWIATKOWSKI 1962a). A chromatographic separation of ^{35}S-labelled material in the metaphyses of 7 day-old rats has shown that 24 hours after the administration of ^{35}S-sulphate the inorganic sulphate could account for no more than 20 % of the ^{35}S (DZIEWIATKOWSKI 1962b).

Further chemical analyses have demonstrated that the ^{35}S-labelled primarily intracellular and subsequently extracellular material consists of a mixture of chondroitin sulphuric acids A and C (THORP & DORFMAN 1963). Possible intermediates in the synthesis are sulphated nucleotides reaching maximum activity in the rat after 6—8 hours, chondroitin sulphate itself reaches maximum specific activity after 24 hours (PICARD ET AL. 1964), i.e. at the time of peak labelling as seen in autoradiography (BELANGER 1956, ENGFELDT & WESTERBORN 1960, DZIEWIATKOWSKI 1962b). The Golgi zone plays a considerable role in the intracellular synthesis of mucopolysaccharides. In four hours the newly synthesized material has been transported into the cartilage matrix (ROHR & WALTER 1966).

One or two days after the administration of ^{35}S-sulphate a considerable amount of ^{35}S is still retained in the cells, although a significant activity is also seen in the extracellular matrix. Six to seven days after labelling the radioactivity has concentrated almost exclusively in the organic matrix (BELANGER 1956, ENGFELDT & WESTERBORN 1960, DZIEWIATKOWSKI 1962b). After 2—3 weeks a weak reaction is detectable in the cartilage matrix and in the trabeculae of the metaphysis (ENGFELDT & WESTERBORN 1960).

In the light of the above mentioned findings ^{35}S- labelled sulphate seems to provide a new medium for an experimental approach to the problem of transverse growth in the epiphyseal cartilage. Such experiments have recently been reported by SOLOMON (1966) who carried out an autoradiographic study of the diametric growth of the epiphyseal plate using ^{35}S-sulphate in growing rabbits.

The results reported by SOLOMON indicated that 6 days after injection of ^{35}S-sulphate the epiphyseal cartilage showed uniform labelling throughout the central part of the plate but at the periphery immediately beneath the perichondrium and extending slightly towards the previously labelled articular cartilage there were clumps of cells much more faintly labelled. From this observation and from the availability time of ^{35}S-sulphate (extending over 2 or 3 days according to SOLOMON) he concluded that the faintly-labelled cells at the periphery of the cartilage plate shown in the Figures published had been added since the injection of the radio isotope. He considered it an evidence of appositional growth from the perichondrium.

The conclusions drawn by SOLOMON as to the growth in diameter of the epiphyseal plate are not consistent with several phenomena occurring in pathological bone growth (LANGENSKIÖLD & EDGREN 1949). Therefore the present authors considered it desirable to re-evaluate the ^{35}S labelling patterns in the epiphyseal cartilage with the particular purpose of elucidating its mechanism of diametric growth.

MATERIAL AND METHODS

The experimental series consisted of 34 rabbits varying in age from 9 to 28 days at the time of administration of the label. Each animal received 3$\mu c/g$ of ^{35}S-sodium sulphate (carrier free. The Radiochemical Centre, Amersham) in a single intraperitoneal injection. The rabbits were killed at intervals ranging from 1 hour to 14 days after the sulphate injection. A total of 350 autoradiograms were analysed from these animals.

Immediately after death the bones to be studied were dissected out and specimens were prepared from the proximal and distal epiphyses of the tibia and the femur, from the proximal epiphysis of the humerus and from the distal epiphysis of the radius. After fixation in 10 % neutral formalin and decalcification in 5 % nitric acid the tissues were embedded in paraffin, sectioned at 6 μ and stained with Weigert's haematoxylin van Gieson.

It was essential for a successful realization of the purpose of this study that the autoradiographic technique adopted should allow estimation of the relative ^{35}S-activities in the different regions within each individual epiphysis. Comparison of labelling intensities from one specimen to another was only of secondary importance. Autoradiography was therefore used mainly as an instrument capable of recording the *distribution patterns* of the labelled material at different intervals after the injection of ^{35}S-sulphate.

The objects analyzed in the autoradiograms consisted of fairly large pieces and were clearly visible to the naked eye. It was thus apparent that high resolution autoradiography suitable for grain counting at the cellular level did not seem suitable for this study. Consequently contact or macroscopic autoradiography was adopted employing X-ray film (Dental X-ray Film No 3P Ilford) for autoradiography.

Specific adjustments of the exposure times seemed necessary for the different preparations because over-exposure could cause blurring of possibly important contrasts in the autoradiographic image.

It was considered advisable to aim always at a similar blackening of the hottest area wherever it happened to be. This approach did not exclude the possibilities of comparing the same area in different preparations because

The results reported by SOLOMON indicated that 6 days after injection of ^{35}S-sulphate the epiphyseal cartilage showed uniform labelling throughout the central part of the plate but at the periphery immediately beneath the perichondrium and extending slightly towards the previously labelled articular cartilage there were clumps of cells much more faintly labelled From this observation and from the availability time of ^{35}S-sulphate (extending over 2 or 3 days according to SOLOMON) he concluded that the faintly-labelled cells at the periphery of the cartilage plate shown in the Figures published had been added since the injection of the radio-isotope He considered it an evidence of appositional growth from the perichondrium

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RESULTS

The results are illustrated in Figures 2—20 In each figure a pair of photographs is seen the lower one is an ordinary histological preparation which has produced the matching autoradiograms in Figures 2 18 The interval between the injection of the ^{35}S sulphate and the killing of the rabbit is indicated below each figure (= T) further details such as the age (= A) of the animals and the exposure time (= E) of the autoradiograms are given in the legends

Judging from the experimental results the distribution of the label at different times after ^{35}S sulphate injection is as follows

1 Within 2 hours after the administration of the sulphate considerable activity has been incorporated in organic matter (fixed and demineralized section see also the data referred to in the introduction) The highest activity occurs in the zone of cartilage cell columns of the epiphyseal cartilage It is worth emphasizing that a slight but distinct difference between the central and peripheral areas of the epiphyseal plate can be seen in the former the density is more intense than in the latter Another point of interest is the fact that on both sides of the intensely labelled zone of cell columns there are narrow layers of cartilage with very little if any activity The upper one of these consists of the layer of the reserve cells

It may be noted further that the perichondrial ring does not exhibit much activity

2 After 24 hours the labelling has obviously reached its maximum judging *from the appearance of the autoradiogram and from the exposure time used* With respect to the distribution of the label there is not much deviation from the earlier autoradiograms A similar difference between the central and peripheral parts of the epiphyseal cartilage is still visible

3 During the next 3 days the labelling patterns have clearly changed In comparison to the 1 day autoradiogram ^{35}S has been included in the metaphysis due to a longitudinal growth of the bone Another obvious change involves a decrease in the labelling intensity in the bony epiphysis (cf the respective exposure times of the autoradiograms)

the density of the autoradiographic image would be proportional to the expo sure time within certain limits In practice exposure times were based on an empirical basis The times applied varied from 1 to 60 days

Another essential requirement for the autoradiographic technique adopted was a consistent method of maintaining close and even contact between radioactive sample and recording emulsion The technique with which good contact was achieved deserves some emphasis Heavy and probably even variable pressure on the emulsion may lead to the artificial formation of silver halides Among these mechanisms are such factors as the pressure itself the bending of the film especially at the border areas of the preparation and chemical interaction The technique evolved for this study is illustrated in Figure 1

Apart from the 31 animals used for the main experimental series of this study ten additional rabbits of the same ages were followed roentgenologically From these animals the longitudinal and transverse growth of the bones was measured during the experimental period

The possibility that a part of the autoradiographic image could have been due to artificial interaction of the tissue with the X-ray film was checked in 3 rabbits which had not been injected with ^{35}S sulphate

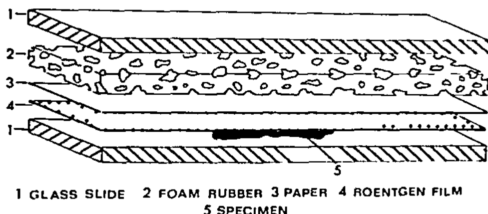


Figure 1 Arrangement for exposure of autoradiograms Contact between the sample and the film is maintained by a rubber string around the block Cutting of the string on sharp glass edges is prevented by paper wrapping

DISCUSSION

Autoradiograms produced one, two and twenty-four hours after the injection of ^{35}S-sulphate give the impression that the peripheral areas of the epiphyseal plate are less active than the central ones. Thus far, the observations seem to agree with the predictions based on the assumption that the epiphyseal plate grows in diameter by apposition from the periphery. It follows from the very low labelling of the perichondrial ring (see Figures 2 and 3) that a supply of cells from it for the transverse expansion of the epiphyseal cartilage would rapidly decrease the peripheral labelling intensity. After four days a further reduction in the peripheral activity due to continuous apposition of lightly labelled cells could be expected. Further reduction in the activity would occur through the synthesis of unlabelled chondroitin sulphate by the transformed cells. The autoradiograms seen in Figures 5, 11 and 18 are not consistent with such a prediction.

Between the fourth and the seventh day a radical change in the labelling patterns occurred. In the peripheral parts of the epiphyseal cartilage radioactivity had not decreased at all in comparison to the central areas. Autoradiograms obtained at twelve and fourteen days after the ^{35}S injection (Figures 11 and 12) provide the final proof that the patterns seen at seven days were not due to any artefact. After considerable diametric growth of the epiphyseal plate, the peripheral parts of it had retained a marked content of ^{35}S (Figure 22).

The idea that the epiphyseal plate grows in diameter by appositional growth from a perichondrium at the periphery is in conflict with these experimental data.

After three weeks the activity, still distinct in the layer of the reserve cells, is seen to decrease at different rates in the different parts of the layer. The rate of loss is more rapid at the periphery (Figures 7 and 16).

The autoradiographic findings can be explained as follows: after the sulphate injection the initial incorporation is proportional to the rate of formation of organic complexes. With respect to the layer of the reserve cells, the label is taken up at a faster specific rate in the peripheral than in

the central regions of the layer However due to the excessive rate of incorporation in the zone of the cartilage cell columns activity differences within the layer of the reserve cells are not recorded in autoradiograms obtained with a relatively short exposure time (Figure 23)

Because of the fast sulphate metabolism in the zone of the cartilage cell columns both the incorporation and the loss must proceed at a fast rate in comparison to other areas The rate of growth in the layer of the reserve cells is much slower This is demonstrated both by the data presented here and by the results obtained with ^{3}H thymidine (RIGAL 1962) Consequently after a time determined by the relative metabolic rates in the different layers of the epiphyseal plate the opposite to the initial labelling intensities is seen (compare Figure 8 with Figure 11) This also applies to the different regions of the layer of the reserve cells

A conclusion drawn from the last mentioned findings is that the *expansion of the layer of the reserve cells occurs faster at the* lateral parts of the epiphyseal cartilage This would seem to be the most plausible explanation of the regional differences in the sulphate metabolism in the layer of the reserve cells It is also consistent with the conclusion reached by RIGAL (1962) on the basis of H-thymidine labelling

The experiments have shown that ^{5}S taken up by the layer of the reserve cells in the epiphyseal plate within a period of a few days is retained in the ground substance *throughout* this layer after its growth in diameter of 70 per cent or more in three weeks This phenomenon can hardly be explained without the assumption of the occurrence of interstitial growth and expansion transversely to the long axis of the bone in the layer of the reserve cells of the epiphyseal plate

SUMMARY

In order to elucidate the question whether the epiphyseal plate grows in diameter by apposition of cells from a perichondrium at the periphery or by interstitial growth ^{35}S-sulphate was injected into thirty four young rabbits and labelling of epiphyseal cartilages was followed by autoradiography. The ^{35}S-sulphate was injected one hour to forty four days prior to the killing of the animal. Labelling patterns in the tibia, the femur, the humerus and the radius were followed by means of contact autoradiography using a technique specially developed for the present purpose.

Initial labelling was strong in the layer of the cartilage cell columns (maximum after about twenty four hours), intermediate in the periosteum of the diaphysis and in a narrow zone surrounding the bony epiphysis. Initial labelling was weak in the articular cartilage, in the perichondrial ring and also in the layer of the reserve cells. It seemed to be very weak in the bony epiphysis, the metaphysis and the diaphysis.

During the first three weeks the labelling patterns changed in a constant and characteristic manner in all bones studied. In about one to two weeks the layer of the reserve cells began to appear as the most intensely labelled area, especially in the peripheral parts of the layer (cf. Figures 5, 6, 11, 12 and 18).

After three weeks the labelling was most prominent in the entire layer of the reserve cells, being most intense in its central parts (cf. Figures 7 and 19). Radioactivity in the layer of the reserve cells was detectable even forty four days after ^{35}S-sulphate administration.

The experiments have shown that ^{35}S taken up by the layer of the reserve cells in the epiphyseal plate within a period of a few days is retained throughout this layer after its growth in diameter of 70 per cent in three weeks (Figure 21 and Figure 20 B). This phenomenon is difficult to explain without the assumption of the occurrence of interstitial growth and expansion transversely to the long axis of the bone in the layer of the reserve cells of the epiphyseal plate.

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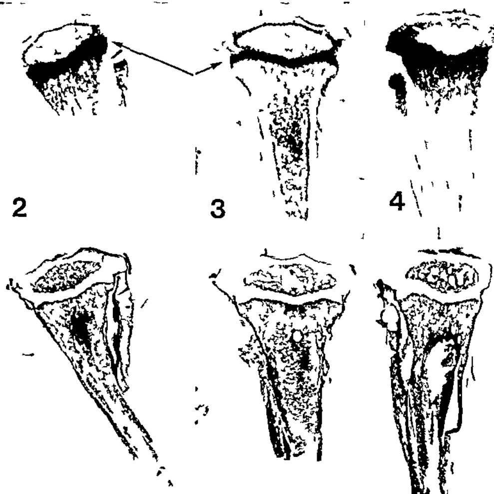
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Glossary of symbols for figures 2—20
T = time of killing of the animal after administration of ^{35}S sulphate (3 $\mu c/g$ body weight)
I = exposure time of the autoradiogram
A = *age of the rabbit at time of sulphate injection*
Figures 2—20 are all reproduced in the same magnification

Figure 2 T = 2 hrs I = 14 days A = 12 days Tibia prox e (e = epiphysis) Initial labelling has been most intensive in the layer of cartilage cell columns of the epiphyseal cartilage In this figure differences between central and peripheral areas of the cartilage are evindently masked due to relative over exposure of the autoradiogram (cf figs 3 8 and 9) Note that the perichondrial zone exhibits low labelling (arrow)

Figure 3 T = 1 day I = 8 days A = 11 days Tibia prox e The border area between the layer of cartilage cell columns and metaphyseal bone is less distinct than in fig 2 radioactivity is also seen in the uppermost parts of the metaphysis Peripheral areas of the epiphyseal plate appear less active than central areas Weak labelling of the perichondrial zone is also clearly seen (arrow)

Figure 4 T = 4 days I = 14 days A = 12 days Tibia prox e Note that the radioactivity now extends down into the metaphysis The epiphyseal plate is fairly evenly labelled throughout its whole transverse diameter

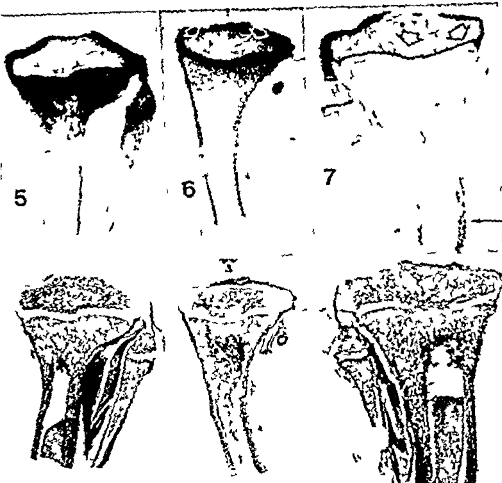


Figure T = ~ days I = 20 days A = 12 days Tibia prox e Note the even distribution of radioactivity between the epiphyseal plate and the metaphysis Peripheral areas of the epiphyseal plate (and the adjacent articular cartilage) appear more intensely labelled than central areas First sign of the prominence of labelling of the layer of the reserve cells can be seen especially in the periphery

Figure 6 T = 9 days I = 20 days A = 12 days Tibia prox e Note that the layer of the reserve cells has become very distinct It is clearly seen in this picture that the bony epiphysis has grown since the administration of ^{35}S-sulfate (arrows)

Figure 7 T = 21 days L = 4o days A = 9 days Tibia prox e (during the 3 weeks the weight of this rabbit increased from 130 g to [illegible]70 g) Note the distinct activity in the layer of the reserve cells and in particular the difference between its peripheral and its central parts (arrows) In the diaphysis one can see the original areas of sulphate incorporation (arrow) indicating the radioactive substance accumulated in areas in which appositional growth of bone is taking place

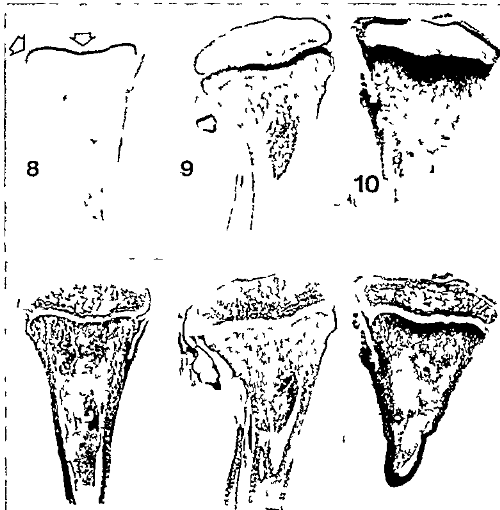


Figure 8 T = 2 hours I = 7 days A = 28 days Tibia prox e Principal incorporation of sulphate in the layer of cartilage cell columns in the epiphyseal plate is evident Note that with a shorter exposure time than in Fig 2 initial labelling appears to be less intense in the periphery than in central areas (arrows) Low activity in the perichondrial zone is also seen

Figure 9 T = 1 day I = 15 days A = 30 days Tibia prox e Differences in sulphate incorporation between central and peripheral areas in the epiphyseal cartilage are particularly distinct

Figure 10 T = 4 days I = 7 days A = 30 days Tibia prox e Note that labelling extends into the metaphyseal bone Differences between central and peripheral areas in the epiphyseal cartilage are no longer distinct (cf fig 4)

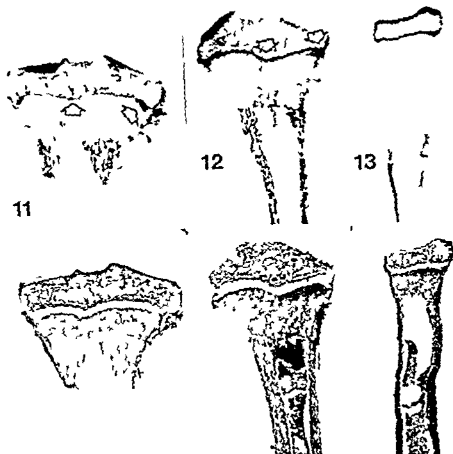


Figure 11 T = 12 days E = 20 days A = 34 days Tibia prox e The layer of the reserve cells has become the most active part of the epiphyseal cartilage especially in its peripheral area (arrows) ^{35}S sulphate incorporated in the metaphysis 12 days earlier is also distinct

Figure 12 T = 14 days E = 24 days A = 30 days Tibia prox e Radioactivity in the reserve cell layer shows a further relative increase Differences between peripheral and central areas are however still detectable (arrows) Note also the label in the diaphysis

Figure 13 T = 21 days E = 45 days A = 14 days Radius distal e The labelling pattern is basically similar to that seen in the tibia The growth in length of the bone after administration of ^{35}S sulphate can be estimated from the activity zone present in the diaphysis

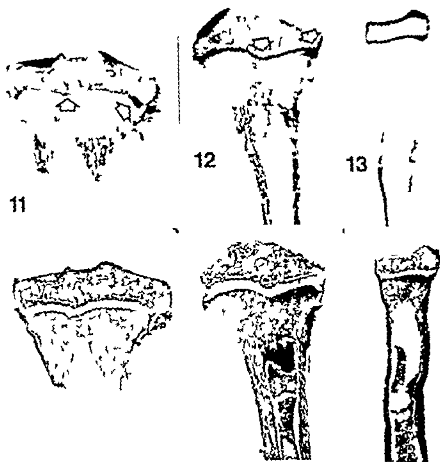


Figure 11 T = 12 days I = 20 days A = 34 days Tibia prox e The layer of the reserve cells has become the most active part of the epiphyseal cartilage especially in its peripheral area (arrows) ^{35}S sulphate incorporated in the metaphysis 12 days earlier is also distinct

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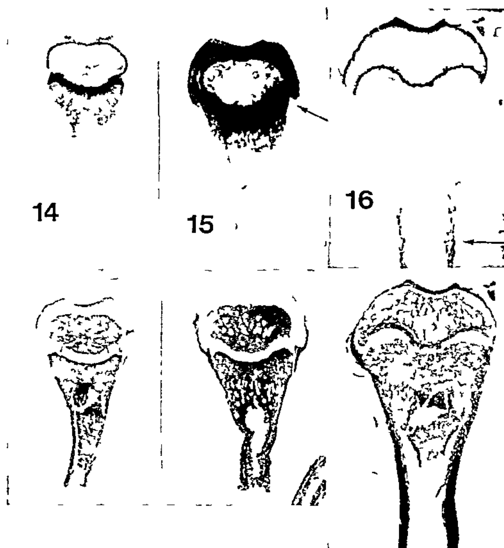


Figure 14 T = 2 hours E = 14 days A = 12 days Femur distal e The initial labelling at the layer of cartilage cell columns by ^{35}S sulphate does not differ from the pattern seen in other bones

Figure 15 T = 4 days E = 14 days A = 12 days Femur distal e Radioactivity is fairly evenly distributed between epiphyseal cartilage metaphysis and articular cartilage Note that labelling in the perichondrial zone remains weak also in this figure (arrow)

Figure 16 T = 21 days E = 45 days A = 9 days Femur distal e Radioactivity in the layer of the reserve cells is as distinct as in other epiphyses Note the marked difference between the central area and the less intense peripheral areas (cf fig 7) Labelled sulphate in the diaphysis is also evident (arrow) ^{35}S is retained in the *ground substance throughout* the layer of the reserve cells even after considerable growth of the plate in diameter

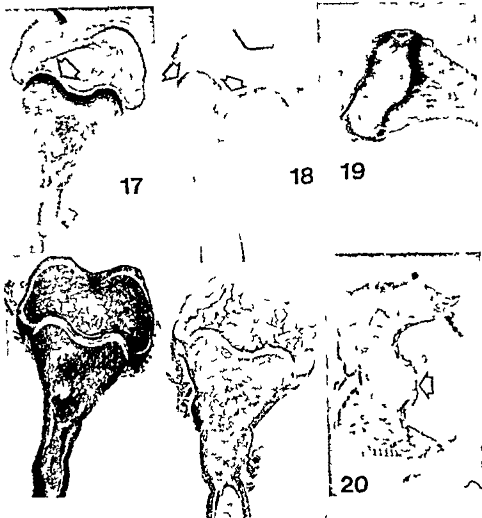


Figure 17 T = 1 hour L = 7 days A = 28 days Femur distale Initial uptake of ^{35}S sulphate has taken place most intensely in the cartilage cell columns Above them the reserve cells are seen as a light zone (arrow) Note that a narrow activity zone can been seen around the bony epiphysis Above the epiphyseal plate it lies close to the layer of the reserve cells

Figure 18 T = 8 days L = 14 days A = 21 days Femur distale The highest concentration of radioactive material begins to be seen in the layer of the reserve cells especially in the periphery (arrows)

Figure 19 T = 9 days L = 20 days A = 12 days Femur distale The layer of the reserve cells exhibits the highest activity The bony epiphysis contains a similar narrow zone of ^{35}S as seen in figure 17 (arrows) indicating the size of the bony nucleus at the time of labelling

Figure 20 T = 44 days L = 60 days A = 20 days Femur distale It can be seen that even 1 5 months after ^{35}S labelling the entire layer of the reserve cells (arrow) yields a positive autoradiogram (note that physical half life of ^{35}S is 87 days)

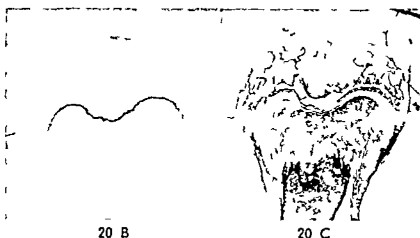


Figure 20 B T=12 days I=60 days A=10 days Femur distal epiphysis 42 days after injection Distinct radioactivity extends throughout the layer of the reserve cells
Figure 20 C Histological section corresponding to 20 B

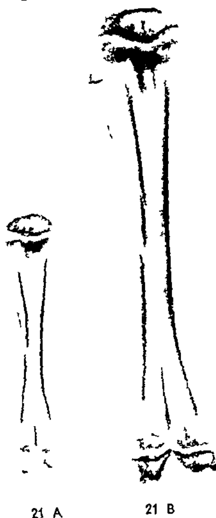
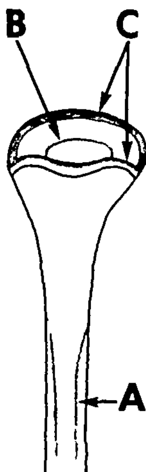


Figure 1 A X ray picture of the tibia in a 14 days old rabbit *B* Tibia in a 35 days old rabbit
Both photographs are in the same proportion to the true size of the tibiae Note that the diameter of the epiphyseal plate is about 70 per cent larger in the older animal This proportion was checked in four other pairs of animals



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Figure Schematic representation of an autoradiogram about 3 weeks after ^{35}S sulphate labelling

A indicates radioactivity in the diaphysis originally incorporated in the periosteum (cf figs 7 13 and 16)

B indicates label which has remained in the bony epiphysis (cf figs [illegible] and 19)

C indicates that the bulk of radioactivity is located in articular cartilage and in particular in the layer of the reserve cells of the epiphyseal plate (cf figs [illegible] 7 13 and 16)

That ^{35}S is retained throughout the layer of the reserve cells after its growth in diameter of 70 per cent is only consistent with the assumption of the occurrence of interstitial growth and expansion transversely to the long axis of the bone in this layer of the cartilage

VEIJO A J VAHVANEN

Rheumatoid Arthritis in the Pantalar Joints

A Follow-up Study of Triple Arthrodesis on 292 Adult Feet

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Rheumatoid Arthritis in the Pantalar Joints

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SUPPLEMENTUM No 107

From the Hospital of the Rheumatism Foundation Heinola, Finland
(Head Professor Veikko Laine M D)

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Helsinki, June 1967

V. Vahvanen

CONTENTS

II PROBLEMS

1 *What are the clinical and radiological changes caused by rheumatoid arthritis in the pantalar joints?* How do the clinical and radiological symptoms and signs in the subtalar and talocrural (TC) joints develop in different duration groups of the disease? What changes appear as the initial signs?

2 *What are the practical consequences for the rheumatoid patient of arthrodesis of the subtalar and midtarsal joints (triple arthrodesis)?*

In order to answer this question it was necessary to follow up both operatively and conservatively treated patients Particular attention was paid to the following points

The possible general activation of the rheumatoid process as a result of operation Changes in the clinical symptoms in both the TC and the subtalar joints The development of osteoporosis and periosteal reaction in the subtalar area after operation The relationship between periosteal changes and the rheumatoid process The development of union and the duration of immobilization The development of the radiological changes in the talocrural joint after triple arthrodesis The anatomical results of operation

3 *Do rheumatoid arthritis or arthrodesis of the subtalar and midtarsal joints cause instability of the talocrucal joint?* If instability appears, how does this influence the function of the foot?

4 *Does arthrodesis of the subtalar and midtarsal joints lead to the development of osteoarthrosis of the talocrural joint?*

5 *What are the functional results of operative treatment?*

6 *What is the most favourable time for the performance of triple arthrodesis from the standpoint of the development of the disease and the best possible result?*

III MATERIAL

Triple arthrodesis including the talocalcaneal talonavicular and calcaneocuboid joints was performed on 229 rheumatic patients at the Hospital of the Rheumatism Foundation Heinola during the years 1953—1964 In 63 cases this operation was carried out bilaterally Thus the total number of feet on which triple arthrodesis was performed was 292 Eighty-one feet belonged to male patients, 211 to female patients The total number of left feet was 140, while the number of right feet was 152 the distribution being thus very even in this respect Triple arthrodesis was carried out on female patients almost three times as often as on male patients The ratio females/males was somewhat higher than the corresponding ratio in rheumatoid arthritis (RA) which is 2/1 according to LAINE (1953)

Furthermore for the sake of comparison a series of conservatively treated feet was also studied This consisted of the less inflamed feet totalling 166 of the above mentioned 229 patients and of 38 feet belonging to a further 38 patients The total number of feet in this series was thus 204, and the total number of patients included in the present study was 267

Both in the text and in the tables the designations Op I and Op II are used for the operatively treated feet Op I stands for the observations made immediately before operation, Op II for those made postoperatively, at follow up Similarly Non-op I means the observations made on the conservatively treated feet at a point of time corresponding to that at which the observations in group Op I were made and Non op II stands for the observations made at follow up examination of the conservatively treated feet

The series comprises only patients whose rheumatoid arthritis began after the age of 15 This age limit was adopted because other investigators e g LAAKSONEN (1966) in his doctor s thesis »A Prognostic Study of Juvenile Rheumatoid Arthritis» and SIEVERS (1965) used 15 years as the borderline between juvenile and adult rheumatoid arthritis

The distribution of the Op I group over different duration groups is shown in Table 1 By duration is meant the time of illness in years from the

TABLE 1 *Distribution of the material according to duration of the disease (= interval in years between the onset of symptoms of RA in the tarsal or ankle joints and operation)*

Sex	Left/Right	<3	4—6	7—10	>10	No of feet
Male	L	16	6	11	8	41
	R	13	9	8	10	40
No of feet		29	15	19	18	81
		35 8	18 6	23 4	[illegible]	[illegible]
Female	L	32	25	15	27	99
	R	40	26	23	23	112
No of feet		72	51	38	50	211
%		34 1	24 2	18 0	23 7	72.3
Total no		101	66	57	68	292
		34 6	[illegible]	19 5	23 3	100 0

onset of symptoms in the joints of the ankle or foot until operation. Initial symptoms in the joints of the toes are disregarded. The distribution is fairly even although the first group (3 years) is the largest. This reflects the endeavour to institute treatment in the initial stage of the disease.

The diagnosis of rheumatoid arthritis was based on the criteria introduced by ROPES et al (1956, 1959) which have been generally adopted and which were accepted by a Committee of the American Rheumatism Association. A diagnosis of "definite rheumatoid arthritis" requires that 5—6 of 11 specified criteria are satisfied, and a diagnosis of "classical rheumatoid arthritis" that 7—8 of these criteria are satisfied. It should be noted however that all patients who showed any of the features listed by ROPES as typical of other diseases were excluded.

The present series includes only "definite" and "classical" cases. In the operatively treated series there were 50 diagnoses of definite RA (21 8 per cent) and 179 (78 2 per cent) of classical RA.

The series included 22 wheel-chair patients with severe lesions. In these cases the goal of the operative program was to rehabilitate the patient as far as possible, i e to make him ambulatory with the aid of crutches.

The mean duration of hospitalization was 101 days. Treatment of this length was found necessary both for the accomplishment of adequate medical therapy and for the performance of surgical procedures with subsequent rehabilitation. At the time of discharge it was often possible to evaluate the

immediate operative result Since the patients of the Rheuma Hospital frequently come from distant domiciles it is sometimes difficult to carry out follow up studies Many patients return later however because of inflammation of some other joint and can thus be followed up for years Of the present patients 150 (65 5 per cent) had been hospitalized more than once

The mean age of the men at onset of rheumatoid arthritis was 35 9 years the mean age of the women 33 3 years The initial symptoms most frequently occurred in the joints of the fingers and toes In the foot, inflammation was not long in spreading to the ankle and other joints

The mean age of the men was 37.8 years that of the women 34 7 years when the first symptoms of rheumatoid arthritis were noticed in the ankle or in the foot proximal to the toes The interval between onset of the disease and involvement of the ankle was 1 9 years among the men and 1 4 years among the women

The mean age of the men at operation was 44 5 years, the mean age of the women 42 4 years The mean interval between the onset of symptoms in the ankle and operation was 6 7 years among the men and 7 7 years among the women

IV METHODS

Previous investigations

The views concerning the range of movement of the TC joint are somewhat conflicting In the present study a dorsal flexion of over 15 degrees and a plantar flexion of at least 40 degrees were regarded as normal According to v Lanz and Wachsmuth (1938 1959), the normal total range is 40—50 degrees according to Steindler (1955) it is somewhat wider This author regarded a dorsal flexion of 15—20 degrees and a plantar flexion of 40—50 degrees as normal In Vainio s (1956) control series the dorsal flexion of the ankle was an average of 12 5 degrees in the men, 11 7 degrees in the women and the corresponding figures for the plantar flexion were 36 1 and 10 6 degrees Niederecker (1959) stated that the total range of movement may be as much as 100 degrees but then the knee is semiflexed and the leg mu cles are not stretched

According to Niederecker (1959) and others the total range of movement of the subtalar joints of the normal foot is about 60 degrees and supination is always wider than pronation In Vainio s (1956) control series this movement was accurately measured the mean values being 12 3 degrees of supination and 20 0 degrees of pronation for the men 15 9 degrees of upination and 23 6 degrees of pronation for the women

In a normal foot bearing weight the maximum size of the angle between the calcaneus and the leg is 5 degrees according to Pitzen (1921) and v Lanz and Wachsmuth (1938) In Vainio s (1956) control group the mean calcaneal valgus angle was 4 6 degrees in the women and 5 1 degrees in the men According to Niederecker (1959) the maximum size of the calcaneal angle is 6 degrees

According to Schede (1924) the axes of the first metatarsus the first cuneiform the navicular and the talus are on the same straight line in a normal foot According to Niederecker (1959) the average angle between the longitudinal axis of the talus and the horizontal weight bearing surface

(the talus floor angle) measured on radiographs of the normal weight bearing foot is 23 degrees In the flat foot the talus floor angle was found to average 32 degrees in congenital cases even more The head of the talus is depressed (subluxated) in these feet, and the longitudinal axis of the talus becomes steadily more vertical When this axis no longer coincides with the axes of the other bones located on the medial ray of the foot there is a break in the line

A classification from 0 to 4 (stages) was used by STEINBROCKER TRAEGER and BATTERMAN (1949) in the evaluation of radiological findings A similar classification from 0 to 4 was used by LAINE (1962) in the evaluation of clinical and radiological findings

The tilting of the talus on stress radiographs has already been examined by many authors These studies will be surveyed in another chapter

SIEVERS (1965) investigation »The rheumatoid factor in definite rheumatoid arthritis» was used as a basis for the evaluation of the rheumatoid factor in this study

LAINE and VAINIO (1964) mentioned in their study that a high erythrocyte sedimentation rate (ESR) is no contra indication to operative procedures and after operations the ESR dropped to the previous level or below it

ROPES et al (1956 1959) suggested the following criteria for the histological diagnosis of RA on the basis of synovial specimens 1 Marked villous hypertrophy 2 Proliferation of superficial synovial cells often with palisading 3 Marked infiltration of chronic inflammatory cells (lymphocytes or plasma cells predominating) with a tendency to form »lymphoid nodules» 4 Deposition of compact fibrin either on surface or interstitially 5 Foci of cell necrosis

According to Ropes, at least three of these criteria have to be satisfied to justify a patho-anatomical diagnosis of »typical rheumatoid arthritis»

Present investigation

Data concerning the present patients were obtained from the following sources

1) Hospital records and patients charts from outpatient departments 2) radiographs 3) laboratory examinations 4) patho anatomical examinations 5) operative findings 6) photographs 7) replies to questionnaires and 8) follow up examinations

In the present study all changes including deformities and X-ray findings were classified under stages 0—4

Evaluation of the clinical observations

Pain Stage 0 No pain at rest Stage 1 Slight pain occasionally after motion or the patient was uncertain on this point Stage 2 Definite moderate pain, occurring intermittently at rest Stage 3 Marked pain Stage 4 Violent, almost continuous pain

Swelling of the ankle and the soft tissues of the foot was evaluated by inspection and palpation Stage 0 No swelling observed Stage 1 Slight swelling or uncertain finding Stage 2 Moderate swelling Stage 3 Marked swelling Stage 4 Excessive swelling

Pain on motion and *weight-bearing* in the TC and subtalar joints This symptom was studied during passive and active movement of the joints by palpation and by recording the patient s reactions to walking Stage 0 No pain Stage 1 Diffuse pain on walking and slight tenderness on palpation Stage 2 Moderate pain on palpation motion and weight-bearing Stage 3 Marked pain on motion and weight bearing a definite limp Stage 4 Very marked pain walking without support or without a considerable limp impossible

Range of motion of the TC and subtalar joints As regards the *TC joint* this implies movement as measured to the nearest degree dorsal and plantar flexion separately The measurements were performed when the knee was maximally stretched Then the movement occurs in a plane perpendicular to the longitudinal axis of the leg 90 degrees being the zero from which the range of movement is measured in both the dorsal and plantar directions No pronation or supination was allowed During measurement the leg and sole of the foot were gently supported The measurement was performed from the lateral aspect of the ankle The evaluation of dorsal flexion was as follows Stage 0 Over 15 degrees Stage 1 10—15 degrees Stage 2 5—9 degrees Stage 3 1—4 degrees Stage 4 No movement Plantar flexion Stage 0 40 degrees or more Stage 1 30—39 degrees Stage 2 20—29 degrees Stage 3 1—19 degrees Stage 4 No movement

Movement of the *subtalar joints* in this study means the combined active movement supination and pronation of the talocalcaneal joint and Chopart s joint The performance of this movement proved to be difficult for many patients however and could sometimes only be accomplished with the assistance of the examiner who helped by gently moving the foot with one hand supporting the leg above the ankle with the other

Pronation and supination of the foot were measured in the plantigrade plane with a square rule The knee was kept in maximal extension and the

talocrural joint was kept at right angles or in the position in which it was anchylosed At follow up examination the subtalar movements were measured by the author

The subtalar movements were evaluated as follows Stage 0 No limitation Stage 1 Uncertain finding or a limitation of up to one third of the normal range (about 60 degrees being regarded as the normal) Stage 2 Limitation up to two thirds Stage 3 Limitation up to three thirds the foot being then rigid Stage 4 No movement

D e f o r m i t y was evaluated as follows Stage 0 No deformity observable on clinical examination Stage 1 Uncertain finding or slight deformity Stage 2 Moderate deformity Stage 3 Severe deformity Stage 4 Extreme deformity

Calcaneovalgus up to 5 degrees (physiological) was classified as stage 0 valgus of 6—10 degrees as stage 1 11—15 degrees as stage 2 16—20 degrees as stage 3 and valgus over 20 degrees as stage 4 The measurements were made with an inclination meter constructed by the author of the same type as was used by VAINIO (1956) for similar measurements The results were corrected taking into account the angulation of the calcaneus in relation to a vertical line drawn from the middle point of the fossa poplitea downward

The degree of valgus position of the calcaneus was measured by determining the angle made by the lateral surface of the calcaneus with the vertical plane when the patient was standing on the floor or another hard surface

The degree of *calcaneal varus* position follows from the above-mentioned measurements When the valgus position is physiological varus is = 0 Stage 1 according to the evaluation used in the present study means that the angle is almost zero Stage 2 = an inward angulation of the lateral surface of the calcaneus of 1—5 degrees, stage 3 = 6—10 degrees and stage 4 = over 10 degrees The measurements were made to the nearest degree When a patient shows varus of the forefoot he is unable to walk on the full sole of the foot he keeps the inner border more or less elevated The metatarsus primus is often elevated Sometimes callosities are present laterally on the sole of the foot Varus of the forefoot was not measured in degrees the severity of the deformity was estimated as it was in the few cases of cavus calcaneus that occurred

At follow up examination attention was, moreover paid to t h e s t a b i l i t y o f t h e t a l o c r u r a l j o i n t The patient s ankle was placed in 90 degrees angulation and the knee in semiflexion the leg proximal to the ankle was firmly held by the left hand of the examiner while the posterior portion of the sole of the foot was supported with his right hand Then

the examiner tried to move the foot from side to side at the ankle In a normal foot there is no lateral movement in the mortise of the TC joint under these conditions, but during the tests a slight but definite »click» was often heard and felt in the ankle as if two wooden blocks had knocked against each other This never caused the patient any pain nor did it seem to affect his walk Furthermore, during the examination the calcaneus was turned inward and outward, with the ankle first in 90 degrees angulation and then in plantar flexion Sometimes abnormal mobility was observed For this reason as many ankles as possible were radiographed under stress

Radiological investigations

The following views were taken

1) An anteroposterior view and 2) a lateral view of the foot also showing the talocrural joint This view was always taken with the patient standing with weight evenly distributed between the feet 3) Anteroposterior views of both talocrural joints were taken simultaneously on the same film with the patient lying on his back on the examination table 4) For the purpose of determining instability of the talocrural joint radiographs were taken while the ankles were subjected to stress These studies were in all cases carried out by the author

Furthermore during hospitalization radiographs of the chest and hands were taken in almost all cases

Special radiological investigations of ankles subjected to stress were performed by the author The procedure was as follows The patient lay on his back on the examination table with each leg in turn fixed to a wooden device by means of four strong screws furnished with broad end plates, as shown in Plate 1 The end plates which were pressed against the skin, were padded with superlon The two proximal screws were firmly tightened against the distal portion of the leg on both sides so as to prevent lateral movement of the leg The distal screws applied against the lateral and medial aspects of the calcaneus were tightened in turn Thus the calcaneus and talus were inverted and everted respectively and when the maximum was reached radiographs were taken in the anteroposterior projection For the sake of uniformity the same exposure values were used as when ordinary anteroposterior views of the ankles were taken The supporting device was fixed to the table by two strong straps which prevented it and at the same time the leg from moving During exposure the ankle was positioned at 90—100 degrees The distal strap was placed on the plantar side of the foot so as

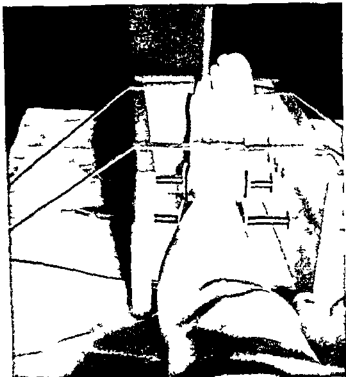


Plate 1 Wooden case lacking front and top parts and furnished with screws between which the foot was fixed on stress examination The case was firmly strapped to the X ray examination table

to prevent the ankle from bending into plantar flexion The inverting and everting effect obtained with the screws is very strong and exposures were made when they were tightened as much as the patient could tolerate for a moment An endeavour was made to apply maximum tightening in all cases The studies were throughout performed without anaesthesia and the ankles were investigated in turn If the ordinary X ray examination revealed union of the talocrural joint after arthrodesis no stress study was performed A radiological stress examination was moreover, carried out with the ankles in maximal plantar flexion (64 ankles)

In addition anteroposterior instability of the talocrural joint was investigated The patient was positioned in lateral recumbency on the side to be studied with the knee in slight flexion and the X ray cassette under the ankle The other leg was bent away from the exposure field The examiner took a firm grip of the distal part of the leg under study with one

hand above the ankle and with the other hand round the heel, pushing it as forcibly as possible forwards, trying to luxate the talus in the anterior direction Both ankles were thus examined in turn without anaesthesia Care was taken not to rotate the ankle nor to invert or evert it, the ankle joint was in slight plantar flexion Just as in the examinations described above, care was taken not to injure the foot The same exposure values were used as in the lateral projection The examination here described was performed on 53 ankles on which triple arthrodesis had been performed and on 68 ankles which had not been operated upon

In order to test the methods of investigation, corresponding radiological stress examinations were carried out on completely normal subjects Further more ordinary anteroposterior and lateral views were taken of normal ankles This control series consisted of members of the hospital staff who had no diseases or lesions of the joints The control material consisted of 60 ankles

It was also found that the radiographs taken of the ankle in different positions (stress examination) were helpful in evaluating erosion By the aid of these it was possible to confirm findings which would have remained uncertain on the basis of ordinary anteroposterior and lateral views alone

Evaluation of the radiographs

Attention was paid to the following features 1) decrease in calcium content 2) narrowing of the joint space 3) erosion 4) periosteal reactions 5) osteoarthrosis 6) alignment changes 7) instability of the ankle joint as estimated from the tilting of the talus during stress examination 8) fusion

Each feature was evaluated as follows Stage 0 = no change stage 1 = *slight uncertain change* stage 2 = *definite change* stage 3 = *marked* change stage 4 = very marked change

1) O s t e o p o r o s i s *The observations were compared with the corresponding findings in the other foot and with previous radiographs of the same foot*

2 J o i n t s p a c e s *of the talocrural joints were measured on the an*teropo terior view to the nearest 0 1 mm using a nonius The measurements were always performed at the middle point of the joint In addition the symmetry of the joint spaces on the lateral view was taken into account Narrowing was classified as stage 2 only when the joint space was clearly diminished in both projections Stage 3 indicates a practically rigid joint or incipient fibrotic anchylosis with a joint space only just distinguishable On evaluat-

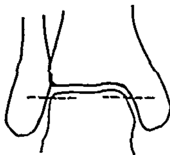


Fig 1 The mortise of the talocrural joint The area above the dotted line is the midpart of the joint the lower part of the mortise consists of a medial and a lateral part Erosion in the midpart of the joint is described as »surface» erosion in the lower part of the mortise as »marginal» (medial or lateral) erosion

ing the change the joint was always compared with the corresponding contralateral joint and with the state on previous radiographs The joints of the foot were studied on lateral views When evaluating the talonavicular joint attention was also paid to the cuneonavicular joint As this is more distal the space is not in any event broader than that of the talonavicular joint

3) E r o s i o n A fresh area of erosion is always very well demarcated on radiographs Later however it may become less distinct and the joint surface may assume a rough appearance owing to the accumulation of calcium and/or hypertrophy (Soila 1958) The distinguishing of erosion at the border between the articular cartilage and the cortical bone and/or in the bone surface may be rendered still more difficult by the occurrence of a periosteal reaction, which may cause marked unevenness cyst-like formations and hypertrophy

The evaluation of erosion was made as follows in respect to the different joints

In the *talocrural joint* the erosive and periosteal changes were separately evaluated in three different areas of the joint i e 1) in the midpart of the joint (surface erosion) 2) in the medial part of the mortise and 3) in the lateral part of the mortise When surface erosion occurs in the TC joint it involves the horizontal joint surface including the two angles of the TC mortise In the present study the medial malleolus and the opposing medial part of the talus are regarded as belonging to the medial part of the mortise the lateral malleolus and the opposing lateral part of the talus as belonging to the lateral part of the mortise (Fig 1)

The erosive changes were classified as follows Stage 0 = No changes observable the surface was smooth even if osteoporosis was present Stage 1 = The surface corresponding to the articular cartilage or the surface of the marginal zones was clearly rough, although definite typical erosion was not yet discernible in the distal parts of the malleoli small cystic formations were sometimes seen Stage 2 = Definite erosion, more abundant cystic formations in the malleolar surface Stage 3 = Deep extensive erosion in a limited area or many small areas of slight erosion the outline of the distal apices of the malleoli was blurred a considerable degree of osteolysis was sometimes present Stage 4 = Marked erosion destruction or large cystic spaces

Erosion of the talocalcaneal calcaneocuboid and talonavicular joints was classified as follows Stage 0 = No changes the joint surface was smooth Stage 1 = Uncertain finding unevennesses possibly present Stage 2 = Slight but definite erosion Stage 3 = A limited area showing marked erosion or several small areas of erosion Stage 4 = Marked destruction

4 Periosteal reaction in this paper means reactive changes of the periosteum either at the margins of the joint and/or for some distance along the bony surface

The periosteum may form sharp spicules projecting upwards or downwards from the margins of the joint, or it may show hypertrophy or even cauliflower like formations These may later become sclerotic owing to the accumulation of calcium

The periosteal changes characterized by roughness of the surface were classified as follows Stage 0 = No changes with the exception of osteoporosis Stage 1 = Slight roughness of the surface Stage 2 = Clearly elevated osteophytes moderate roughness of the surface definite periosteal growth Stage 3 = Marked periosteal changes marked active reaction Stage 4 = Very marked reactive changes

When the posterior process of the talus was clearly enlarged, this was noted as a periosteal change of the tc joint This lesion may restrict the *movement of the talocrural joint*

5 Osteoarthrosis It was difficult to classify the findings by different stages Just as in the case of osteoporosis the evaluation was greatly hampered by technical differences between the radiographs taken at different times When the accumulation of calcium had clearly increased and sclerosis was present the change was discernible Slight changes could not be distinguished with certainty

The osteoarthrotic changes were also classified by stages 0—4 stage 1 standing for an uncertain finding and stage 2 for a definite finding

6 Alignment changes When the ligaments and joints of the foot are damaged by RA weight bearing gradually leads to structural changes and deformities These appear on radiographs taken in lateral projection during weight bearing as lowering of the arch of the foot The position of the bones in relation to each other is altered In the present investigation the changes in the longitudinal axis of the calcaneus and talus were studied on all lateral views The angle between the longitudinal axis of the talus and the weight bearing plane (the horizontal plane) was measured to the nearest degree

7 Tilting of the talus In the present study the tilting of the surface of the talus in relation to the articular surface of the tibia was measured to the nearest degree The tilting of a straight line passing the two tuberculi of the talus against a line passing the depressions of the tibial articular surface, which correspond to the tuberculi of the talus was measured with a protractor

The results were classified by stages 0—4 as follows Stage 0 = No change or a change of less than 1 degree Stage 1 = Talar tilt of 1—5 degrees Stage 2 = Talar tilt of 6—10 degrees Stage 3 = Talar tilt of 11—15 degrees Stage 4 = Talar tilt of over 15 degrees

When lateral views were taken during the radiological stress examination an attempt was made to luxate the talus forward by pressing the calcaneus backward Subluxation would be indicative of insufficiency in the ligaments The radiographs showed whether the symmetry of the articular surfaces of the talus and tibia was disturbed by the stress A shift in position of the talus was evaluated by comparing the location of constant points on the talus and tibia Both ankles were always radiographed and the radiographs were compared The result was regarded as positive only when the talus was clearly dislocated forward and the articular surfaces showed lack of symmetry The distal tibiofibular syndesmosis was studied on antero-posterior views of the ankle It had clearly broadened in only two cases, but these ankles were clinically stable and the tissues showed cicatrices resulting from protracted disease On follow up investigation the location of the staple and the possible changes occurring in the surrounding bone were closely studied on the radiographs

8 Fusion The following joints were examined from the standpoint of fusion the talocrural talocalcaneal calcaneocuboidal talonavicular and cuneonavicular joints

The joint was regarded as completely fused when no joint space was discernible the bone trabeculae having grown homogeneously across the

site of the space When part of the articular surface was visible and the trabeculae had grown over the joint space only in certain areas, the joint was regarded as showing partial union When the joint was clearly open in spite of operation the term »non union» is used, and when movement was observed, the term »pseudarthrosis» is applied

Laboratory findings

From the standpoint of the present study the most interesting features were the occurrence of the rheumatoid factor and the behaviour of the erythrocyte sedimentation rate in the patients operated upon The Hgb the postoperative temperature, the results of physical examination (e g height and weight which may be of significance for the evaluation of the operative results) were also recorded, however

Special attention was paid to the Waaler Rose and the latex fixation tests

In the present study the serological tests for the rheumatoid factor were of importance mainly for the reason that a positive result is one of the criteria listed by the Committee of the American Rheumatism Association Rheumatoid factor was regarded as being present if the reaction to the latex fixation test was clearly positive or/and the Waaler-Rose titre was elevated at least in a dilution of 128 If Waaler Rose was positive in a dilution of 500, the disease was regarded as very active from the serological standpoint In 180 cases (85 2 per cent of 211 examined patients) the reaction to the latex fixation test or Waaler Rose was significantly positive

Histological criteria

The present material of histological specimens was examined by Ritama, Helsinki Synovial specimens were taken from 112 (38 6 per cent) of the 292 feet on which triple arthrodesis was performed

The following criteria were applied by Ritama 1 The occurrence of characteristic vasculitis 2 Infiltration of plasma cells and lymphocytes with a tendency to form folliculoid foci without a germinal centre 3 Proliferative activity often with palisading of the marginal synovial cells 4 Occurrence of necrosis

According to Ritama a histological specimen from some part of an inflamed joint, particularly the talocrural joint may even be normal in appearance In any event the degree of inflammation varies in different areas of

the same specimen Hence the evaluation must be based on the total appearance of the specimen In chronic cases the diagnosis offers greater difficulties Typical round cell infiltration may be lacking in cases of old standing but proliferative cellular activity and tissue necrosis may also occur in chronic cases The intermittent character of the disease is reflected in the histological picture

Statistical methods

The results have chiefly been expressed as arithmetical means and percentages In connection with certain means the standard errors have also been indicated

In testing the statistical significance of the results the levels 05 (significant) 01 (most significant) and 001 (highly significant) were used When possible *one-tailed tests of significance were applied otherwise two tailed test*

On comparing the various groups obtained by classifying the material according to the duration of the disease the significance of the differences between the means was tested using the one way variance analysis (FERGUSON 1966 p 289—291) The significance of the trend reflecting the development of the disease was also tested by variance analysis applying linear trend analysis (FERGUSON 1966 p 313—315) As regards the results of these tests the number of the degrees of freedom the F value and the corresponding level of significance are mentioned in the text On account of their skew distribution certain variables were analysed by the non parametric equivalents of the parametric methods mentioned above Instead of parametric variance analysis the variance analysis of KRUSKAL and WALLIS based on ordinal numbers was applied (FERGUSON 1966 p 362—363) This *means that the significance of the results* was determined by means of the χ^2 distribution The χ^2 value obtained and the corresponding level of significance are indicated in the text As an equivalent of linear trend analysis the non parametric trend analysis suggested by Ferguson (FERGUSON 1966, p 366—367) was applied The significance of the result was then evaluated on the basis of the normal distribution and in the text the z value referring to the normal distribution and the corresponding level of significance are indicated

The significance of the difference between the results of two different determinations performed by one and the same person was tested by the t test of dependent groups (FERGUSON 1966, p 169—171) The t value and the corresponding level of significance are mentioned in the text

Owing to the skew distribution of the variables in question, the significance of the difference between the mean values obtained in different groups was tested by the U test of MANN and WHITNEY, which is based on ordinal numbers (FERGUSON 1966 p 358—360) The significance of the result was evaluated on the basis of the normal distribution The z value and the corresponding level of significance are indicated in the text

V. PREOPERATIVE CLINICAL FINDINGS

Previous investigations

Swelling, pain and range of motion. Tenderness of the inflamed joints, pain at rest, pain on motion and swelling of the soft tissues are very typical symptoms and signs of rheumatoid arthritis, as has been observed by many authors e.g. Laine (1953, 1956, 1962), Copeman (1955), Ropes et al. (1956, 1959), Cobb et al. (1957, 1960), Ansell and Bywaters (1959), Kuhns (1960), Berkowitz et al. (1961), Hollander et al. (1961), Kellgren (1962). These symptoms are also among the criteria for the diagnosis of rheumatoid arthritis adopted by the American Rheumatism Association (1956, 1959).

Isemein and Fournier (1952, 1963) pointed out that evolution of the rheumatoid process leads to anchylosis which is complete when the two bones fuse.

Vainio (1956) established that dorsal and plantar flexion of the ankle as well as subtalar motion (inversion and eversion) were clearly reduced in both men and women with increasing duration of RA. Of the pantalar joints the talonavicular joint was most often affected, but anchylosis was found to be a late change. Soila (1958) also stated that bony anchylosis is a late change, and he found, moreover, that the talocrural and talocalcaneal joints were very resistant to ossification.

Deformities. As was stated by Vainio (1956), the most frequent deformities of the foot caused by rheumatoid arthritis are: 1) Pes planovalgus. 2) Pes varus, i.e. varus deformity of the hindfoot (the calcaneus) or varus of the forefoot. These features may occur in the same foot, varus position of the forefoot being associated with pes planovalgus. 3) Pes equinus, either in the form of a pure equinus deformity or associated with a varus-valgus component. 4) Pes cavus or calcaneus, which may be associated with varus or valgus. 5) Flail foot, which is of common occurrence in juvenile rheumatoid arthritis.

HARALDSSON (1962), in a follow up investigation of operatively treated planovalgus feet in children utilized NIEDERECKER's observations in evaluating the depression of the medial arch of the foot.

LORENTZEN (1963) stated that valgus deformity may develop at a very early stage, and that it may be due to spasm of the peroneus muscles caused by the inflammation.

ISEMEIN and FOURNIER (1963) also found that downward displacement of the talus was very common in RA, and that the foot sometimes became flat as a result.

Present investigation

The subtalar joints

Swelling

The degree of swelling is dependent on the activity of the disease and weight bearing. Furthermore, the occurrence of swelling is influenced by circulatory factors. Rheumatoid patients, however, also show a persistent swelling due to periarticular soft tissue thickening caused by the inflammation. During the active stage of the disease abundant formation of intercellular and intra-articular fluid may occur. The soft tissue thickening caused by RA is encountered round the TC joint of the ankle, round the malleoli, along the tendons, and in the area of the tarsal sinus. Swelling of the tarsal sinus is a very typical feature. Furthermore, soft tissue thickening also occurs round the anterior tibial, peroneal and Achilles tendon. The area of the tendons located behind the medial malleoli is also frequently swollen (Figs. 2, 3, 4).

Even after the inflammation has subsided, swelling observable by inspection often remains in these typical sites. The synovial masses in the joints prolapse in the direction where the joint capsules and articular ligaments best give way, i.e. to the lateral side of the joint. In addition to soft tissue thickening, tenosynovitis and the hyperplastic synovial tissues prolapsing from the joints affect the configuration of the surface. In chronic cases deformation of the joints and osteoarthrosis also cause swelling after stress. In the present series of operatively treated feet swelling was observed in all cases. In 287 feet (98.3 per cent) the swelling was moderate or marked while in five feet slight thickening was seen on the lateral side of the ankle in the area of the tarsal sinus. In these cases the inflammation had become chronic and caused slight changes in the ankle joints. As may be seen in

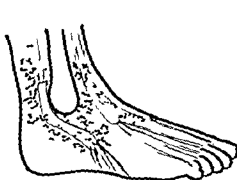


Fig 2

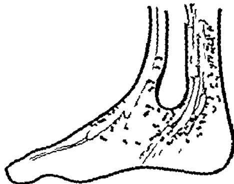


Fig 3

Fig 2 The lateral aspect of the foot The most marked swelling occurs round the lateral malleolus particularly anteriorly underneath and posteriorly and round the peroneal and Achilles tendons Marked swelling al o occurs in the area of the tarsal sinus The ten don heaths are thickened

Fig 3 Medial a pect of the foot As a rule swelling is less than in the lateral aspect but when it occurs it is typically located round the malleolus and follows the tendons in par ticular

Fig 4 Anteroposterior a pect of the foot Swelling is most marked round the malleoli and adjacent tendons

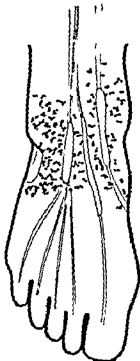


Fig 4

TABLE 2 *Swelling, pain on motion and total range of movement preoperatively in the subtalar joints in the different duration groups*

Duration groups (years)	No of feet	Swelling Stages 0	1	2	3	4	Pain on motion Stages 0	1	2	3	4	Total range of movement Stages 0	1	2	3	4
<3	101	0	0	31	66	1	0	0	6	19	46	0	6	37	58	0
		—	—	33 7	65 3	1 0	—	—	6 1	18 5	45 4	—	6 1	36 5	57 4	—
4–6	66	0	0	[illegible]	44	1	0	1	2	28	35	0	3	17	45	1
	%	—	—	31 8	66 7	1 5	—	1 5	3 0	[illegible]	53 0	—	[illegible]	25 8	68 2	1 5
[illegible]–10	7	0	0	[illegible]2	34	1	0	0	3	31	[illegible]0	0	1	12	44	0
		—	—	38 5	59 7	1 8	—	—	5 2	59 7	35 1	—	1 8	27 1	77 1	—
>10	[illegible]	0	5	[illegible]	34	1	2	1	5	33	27	0	0	18	19	1
		—	[illegible]	41 1	50 2	1 5	3 0	1 5	7 2	18 5	39 8	—	—	[illegible]6 5	7[illegible] 0	1 5
Total	[illegible]	0	[illegible]	105	178	4	2	2	[illegible]	144	128	0	10	84	196	2
		—	1 7	[illegible]	61 0	1 4	0 7	0 7	[illegible]	49 3	43 8	—	3 4	28 8	67 1	0 7

Table 2, these five chronic cases belonged to the over 10 years duration group

Pain on motion and tenderness

Tenderness and pain vary with the intensity of the disease In the active stage the inflammation may cause pain even at rest but as a rule this is not very acute In the present series of feet on which triple arthrodesis was to be performed (292) moderate or marked pain at rest was experienced in 182 (62 3 per cent) according to the patients statements In the remaining cases the patients indicated that they experienced no pain at rest Walking was associated with marked pain in 144 feet (49.3 per cent) in which moderate pain occurred on motion even without weight-bearing Very marked pain on motion without weight bearing was present in 128 feet (43 8 per cent) In these the pain associated with weight bearing was so acute that walking especially outdoors was impossible without the aid of sticks In 16 feet only (5 5 per cent) was the pain on motion and weight-bearing moderate In four cases (1 4 per cent) the statement regarding pain was uncertain In these four cases no movement or very slight movement was observed in the subtalar joint In Table 2 pain is correlated with the duration of the disease The duration was over ten years in three of these four cases, and over three years in one

Pain was a salient feature in all duration groups In the last two groups however a decrease in pain was noticeable in the severest stage (stage 4) This phenomenon is obviously due to destruction of the cartilage and to anchylosis of the joints corresponding to a marked decrease in the range of motion in stages 2 and 3 in the last duration group as may be seen in Table 2 Pain on motion was a prominent feature even in the first duration group all feet belonging to this group being painful

Range of motion

Rheumatoid arthritis leads to a reduction in the range of motion of the joints which initially is due to the swelling and to avoidance of movement because of the pain Later changes in the joint surface narrowing of the joint space erosions and loss of cartilage gradually result in anchylosis In the present study a definite decrease of inversion — supination and eversion — pronation (total motion) of the ankle was observed in 282 feet (96 6 per cent) Thus there were only 10 feet (3 4 per cent) in which a decrease in the range of motion was not observed with certainty or no clear statement to

this effect was found in the hospital records In 84 cases (28 8 per cent) the range of motion was moderate and in 198 cases (67 8 per cent) lateral motion was greatly reduced (the foot being rigid) or did not occur

Table 2 discloses a gradual decrease in the range of motion with increasing duration of the disease the range became slighter after six years This is due to the development of fibrous anchylosis Entirely immobile, anchylotic subtalar joints were observed in only two cases which shows that the progression toward bony anchylosis is very slow As long as the power of movement is preserved, the foot is painful on weight bearing

Deformities

The distribution of preoperative deformities in the present series of 292 operatively treated feet is shown below

Deformity	Stages 0–1		Stages [illegible]–4	
	No of feet	[illegible]	No of feet	
Planovalgus (flat foot)	37	[illegible]	[illegible]	[illegible]
Calcaneovarus	[illegible]	90 8	[illegible]	[illegible]
Varus of the forefoot	[illegible]	80 6	[illegible]	19 4
Cavus or calcaneocavus	[illegible]	93 1	[illegible]	6 9

Varus deformities were associated with planus and cavus Varus of the forefoot was most frequently associated with pes planovalgus The various deformities were combined as follows

Planovalgus (in 3[illegible] feet combined with varus of the forefoot)	[illegible] feet	[illegible]
Calcaneovarus (in [illegible]0 feet combined with varus of the forefoot and in 10 feet combined with pes calcaneocavus)	[illegible] feet	[illegible]
Cavus calcaneocavus	10 feet	3 [illegible]
Total	[illegible] feet	100 0 [illegible]

All planovalgus feet of course showed depression of the longitudinal arch of the foot In 35 feet (12 0 per cent) the arch of the foot was completely depressed, flat foot being present In certain cases the depression of the talus was so marked that the region of the Chopart joint was the lowest point of the foot the first to touch the ground, the fore- and hindparts being elevated This is called a »rocker bottom foot« Ninety three feet (31.8 per cent) showed severe planovalgus the sole of the foot being rather like a board



Plate Feet of a rheumatic patient showing extreme planovalgus Anterior view



Plate 3 Posterior view of the same feet as in plate 2

In 127 feet (13 6 per cent) the deformity was moderate definite depression of the arch of the foot being observed In 29 cases (9 9 per cent) no definite depression of the arch of the foot was observed, or it was very slight, and 8

feet (2.7 per cent) appeared to be normal also on weight bearing (Table 4).

In the varus feet, too, slight or moderate depression always occurred, except in 10 feet exhibiting cavus. The present series clearly shows that planovalgus is by far the most typical deformity of the RA foot. Bending of the forefoot into an obvious varus position was of frequent occurrence, being encountered in almost every fifth case. This phenomenon is an essential feature associated with the development of planovalgus.

In the present study the talus floor angle was measured on the lateral radiographs of 227 weight bearing feet in the operatively treated series and 170 in the conservatively treated series. In the former, the angle varied from 15 to 64 degrees, the mean being 30.6 degrees. The talus floor angle of the other, healthier foot varied from 12 to 48 degrees, the mean being 28.0 degrees (Table 3). According to NIEDERECKER (1959) the corresponding mean value in normal feet is 23 degrees. In the present small control group of entirely normal feet the mean talus floor angle was 21.5 degrees (the range being from 15 to 25 degrees). In this respect the difference between the feet which were to be operated upon and the contralateral feet was very slight.

In Table 4 the development of the planovalgus deformity is correlated with the duration of the disease. It appears that planovalgus is an early change developing within the first three years of the illness. Then the deformity becomes rigid, no further major changes being possible. Only in the most advanced stage (stage 4) is there any steady impairment of the deformity (rocker bottom foot) with increased duration of the disease. In *Table 6 the relationship is statistically analysed. The differences between* the values in the various duration groups were insignificant, which shows that only slight changes occurred during the course of the disease. *The deformity developed within three years from the onset of RA.*

The varus and cavus deformities seemed to follow similar patterns of development, no marked differences being observable between the different duration groups (Table 5). As the number of cases was small, the statistical significance was not tested.

TABLE 3. *Talus — floor angle (on weight bearing)*

Group	No. of feet	Range	Mean value
Op. I	227	15 — 64	30.6
Non op. I	170	12 — 48	28.0
Controls	36	15 — 25	21.5

TABLE 4 *Preoperative distribution of deformities over different duration groups*

Duration groups (years)	No of feet	Planovalgus None	Planovalgus Slight	Planovalgus Moderate	Planovalgus Severe	Planovalgus Extreme	Calcaneovarus None	Calcaneovarus Slight	Calcaneovarus Moderate	Calcaneovarus Severe	Calcaneovarus Extreme	Varus of the fore foot None	Varus of the fore foot Slight	Varus of the fore foot Moderate	Varus of the fore foot Severe	Varus of the fore foot Extreme	Cavus calcaneocavus None	Cavus calcaneocavus Slight	Cavus calcaneocavus Moderate	Cavus calcaneocavus Severe	Cavus calcaneocavus Extreme
<3	101	[illegible]	7	4[illegible]	31	10	89	4	5	3	0	8[illegible]	2	13	1	0	9[illegible]	1	8	0	0
	%	4.9	6.9	41.6	33.7	9.9	88.1	4.0	4.9	3.0	—	81.[illegible]	2.0	12.8	1.0	—	91.1	1.0	7.9	—	—
4–6	66	3	6	3[illegible]	23	2	57	3	3	3	0	[illegible]0	1	8	6	1	6[illegible]	0	3	1	0
		4.[illegible]	9.1	48.5	34.9	3.0	86.[illegible]	[illegible]	4.5	[illegible]	—	7[illegible].8	[illegible]	[illegible]	9.1	1.[illegible]	[illegible]4.0	—	4.5	1.5	—
7–10	[illegible]7	0	8	[illegible]	16	8	53	0	3	1	0	1[illegible]	1	8	3	0	53	0	2	2	0
	%	—	14.0	14.0	[illegible]8.0	14.0	93.0	—	5.[illegible]	1.8	—	[illegible]9.0	1.8	14.0	5.[illegible]	—	93.0	—	3.[illegible]	3.[illegible]	—
>10	68	0	8	[illegible]	[illegible]0	15	56	3	4	[illegible]	0	5[illegible]	2	8	6	0	64	0	3	1	0
	%	—	11.8	36.8	29.4	[illegible]	8[illegible].5	4.4	5.9	7.[illegible]	—	[illegible]6.5	3.0	11.7	8.8	—	94.1	—	4.4	1.[illegible]	—
Total	292	8	[illegible]9	1[illegible]7	[illegible]3	3[illegible]	[illegible]	10	1[illegible]	12	0	[illegible]9	6	37	19	1	71	1	16	4	0
		[illegible]7	[illegible]9	43.6	31.[illegible]	1[illegible].0	87.[illegible]	[illegible]	[illegible]	4.1	—	78.5	2.1	1[illegible]	6.[illegible]	0.3	[illegible].8	0.3	[illegible]	1.1	—

TABLE 5 *The distribution of varus and cavus deformities (stages 2—4) over the different duration groups*

Deformity	No of cases	0—3 yrs	4—6 yrs	7—10 yrs	>10 yrs
Calcaneovarus	27	8	6	4	9
Varus of the forefoot	57	17	15	11	14
Cavus calcaneocavus	20	8	4	4	4

TABLE 6 *Preoperative distribution of planovalgus in the different duration groups Analysis of statistical significance*

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	*4.04*	*3*	*1.35*	*2.11*	*insignificant*
Linear	1.95	1	1.95	3.05	"
Deviation	2.09	2	1.05	1.64	"
Within	182.93	288	0.64		
Total	186.97	291			

$M_1 =$ [illegible] $M_2 =$ [illegible]33 $M_3 = 2.49$ $M_4 =$ [illegible]

TABLE 7 *Deformities in the conservatively treated feet (group Non-op I, total no. of feet 204)*

Deformity	Stages 0—1 No of feet		Stages 2—4 No of feet	
Planovalgus (flat foot)	41	20.1	163	79.9
Calcaneovarus	194	95.1	10	4.9
Varus of the forefoot	190	93.1	14	6.9
Cavus calcaneocavus	197	96.6	7	3.4

TABLE 8 *The distribution of combined deformities in 204 conservatively treated feet (group Non-op I)*

Planovalgus (in 9 cases combined with varus of the forefoot)	163 feet	79.9
Calcaneovarus (in 5 cases combined with varus of the forefoot)	10 feet	4.9
Cavus calcaneocavus	7 feet	3.4 *
Total no	180 feet	87.2 *
No deformities	24 feet	12.8

TABLE 9 *The distribution of planovalgus (stages 0—4) over the different duration groups in the conservatively treated series (group Non-op I)*

Duration groups (years)	No of feet	Stages 0—1		Stages 2—4	
<1	33	10	30 3 %	23	69 7
2—3	46	8	17 4 %	38	82 6
4—6	32	9	28 1	23	71 9
7—10	41	6	14 6	35	85 4
>10	52	8	15 4 %	44	84 6
Total	204	41	20 1 %	163	79 9

Summary

The feet which were to be operatively treated (Op I group) nearly all showed moderate or severe deformity mostly planovalgus which was present in 87 4 per cent Severe varus or cavus deformities were hardly ever observed Planovalgus is clearly the dominant deformity of the adult RA foot In the present series plano valgus was moderate in 127 feet (43 6 per cent) severe in 93 feet (31 8 per cent) and extremely severe in 35 feet (12 0 per cent)

In the *conservatively* treated feet (Non op I group) the development of deformities showed a similar pattern but severe forms were markedly less frequent (Tables 7 8 9) *The symmetric involvement of both feet clearly appears from the fact that moderate or severe planovalgus was present in 87 4 per cent of the Op I group and in 79 9 per cent of the Non op I group* Nor were any definite differences between the various duration group observed in the Non op I group This also reflects the development of planovalgus during the first few years of the disease The occurrence of planovalgus in 69 7 per cent of feet in the under one year s duration group reveals the rapid development of this deformity (Table 9)

The difference in the talus floor angle between the Op I and Non-op I groups is also indicative of the somewhat slighter degree of severity of plano valgus in the latter The strikingly high mean value for the talus floor angle in both groups shows the marked depression of the talus and at the same time constitutes evidence of the violence of the inflammation which secondarily leads to the development of flat foot

The talocrural joint

Swelling

The swelling of the tarsal sinus and the surrounding tissues is combined with the swelling of the TC joint. As regards the location of the swelling no sharp distinction can be made, the TC and talocalcaneal joints being closely connected by the joint capsules and articular ligaments. The lateral ligaments of the TC joint are not readily distinguished from their capsules. The inflamed tissue of the tarsal sinus surrounds the anterior talofibular and calcaneofibular ligaments. According to BROSTRÖM et al. (1965) an open anatomical connection between the TC joint and posterior part of the talocalcaneal joint is sometimes normally present (in about 15 per cent). Consequently, inflammation of the subtalar joints also affects the TC joint capsule and obviously irritates the synovial aspect of the latter. In the present series of operatively treated feet, swelling of the talocrural region was observed *in 186 ankles (63.7 per cent). No swelling was discovered*, or the finding was uncertain, in 106 ankles (36.3 per cent). No case of the severest degree of swelling was observed.

Table 10 shows the distribution of the various degrees *of swelling in the* different duration groups. In this respect, too, the first duration group had almost the highest ratio (67.3 per cent). A higher ratio (73.6 per cent) was only obtained, for some reason or other, in the third duration group (a reflection of the variability in the progression of the disease). In the last (fourth) duration group, swelling was only noted in 51.3 per cent of cases. This pattern corresponds to the distribution of pain in the various duration groups.

Pain on motion and tenderness

According to the hospital records, pain on motion and weight bearing was present in the TC joint of 157 ankles (53.8 per cent). The remaining 135 ankles (46.2 per cent) were either entirely painless or the symptom was uncertain. *The frequent occurrence of pain is striking, considering that the* material was collected mainly with a view to examining the symptoms of the subtalar joints. In many cases the patient's statement regarding the *presence of pain was uncertain*, particularly as regards its location. Movement of the TC joint often feels painful when the subtalar joints are violently inflamed, or the whole ankle is swollen. The pain caused by weight bearing is still more difficult to distinguish from subtalar pain. In the whole series severe pain of the TC joint was only noted in 31 ankles (10.6 per cent) and in no case was pain of stage 4 observed.

TABLE 10 Preoperative swelling pain on motion and range of movement in the talocrural [joint] in the different durati[o]n groups

Duration groups (years)	No of feet	Swelling Stages 0	1	2	3	4	Pain on motion Stages 0	1	2	3	4	Dorsiflexion Stages 0	1	2	3	4	Plantar flexion Stages 0	1	2	3	4
<3	101	11	[illegible]	58	10	0	21	22	47	8	0	2	56	[illegible]	1	0	30	13	[illegible]	7	0
		10.9	21.8	57.4	9.9	—	20.8	21.8	46.5	7.9	—	1.8	55.4	18.0	1.8	—	29.7	12.6	20.8	6.9	—
4–6	66	8	17	3[illegible]	9	0	12	18	[illegible]	7	0	13	3[illegible]	16	5	0	16	[illegible]6	23	1	0
		12.1	25.8	48.5	13.6	—	18.2	27.2	41.0	10.6	—	19.7	48.5	24.2	7.6	—	24.2	39.4	34.9	1.5	—
7–10	57	5	10	37	5	0	7	13	28	9	0	10	7	15	4	1	5	[illegible]	23	5	0
		8.8	17.6	64.9	8.8	—	[illegible]	22.8	[illegible]	[illegible]	—	17.6	47.4	26.2	7.0	1.8	8.8	[illegible]	40.3	8.8	—
>10	68	9	21	26	9	0	15	21	22	7	0	14	28	19	5	2	12	27	22	6	1
		13.1	35.6	38.2	13.1	—	[illegible]	[illegible]	[illegible]	10.3	—	20.8	41.1	7.9	7.2	3.0	17.8	39.8	31.1	8.8	1.5
Total	92	33	73	1[illegible]3	33	0	55	80	126	31	0	59	143	69	18	3	63	120	89	19	1
		11.3	25.0	52.4	11.3	—	18.8	27.4	43.2	10.6	—	20.2	49.0	23.6	6.2	1.0	21.6	41.1	30.5	6.5	0.3

The talocrural joint

Swelling

The swelling of the tarsal sinus and the surrounding tissues is combined with the swelling of the TC joint. As regards the location of the swelling no sharp distinction can be made, the TC and talocalcaneal joints being closely connected by the joint capsules and articular ligaments. The lateral ligaments of the TC joint are not readily distinguished from their capsule. The inflamed tissue of the tarsal sinus surrounds the anterior talofibular and calcaneofibular ligaments. According to BROSTRÖM et al. (1965) an open anatomical connection between the TC joint and posterior part of the talocalcaneal joint is sometimes normally present (in about 15 per cent). Consequently, inflammation of the subtalar joints also affects the TC joint capsule and obviously irritates the synovial aspect of the latter. In the present series of operatively treated feet, swelling of the talocrural region was observed in 186 ankles (63.7 per cent). No swelling was discovered or the finding was uncertain in 106 ankles (36.3 per cent). No case of the severe 3 degree of swelling was observed.

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According to the hospital records, pain on motion and weight bearing was present in the TC joint of 157 ankles (53.8 per cent). The remaining 135 ankles (46.2 per cent) were either entirely painless or the symptom was uncertain. The frequent occurrence of pain is striking, considering that the material was collected mainly with a view to examining the symptoms of the subtalar joints. In many cases the patient's statement regarding the presence of pain was uncertain, particularly as regards its location. Movement of the TC joint often feels painful when the subtalar joints are violently inflamed or the whole ankle is swollen. The pain caused by weight bearing is still more difficult to distinguish from subtalar pain. In the whole series severe pain of the TC joint was only noted in 31 ankles (10.6 per cent) and in no case was pain of stage 4 observed.

TABLE 10 *Preoperative swelling, pain on motion and range of movement in the talocrural joint in the different duration groups*

Duration groups (years)	No of feet	Swelling Stages 0	1	2	3	4	Pain on motion Stages 0	1	2	3	4	Dorsiflexion Stages 0	1	2	3	4	Plantar flexion Stages 0	1	2	3	4
–3	101	11	22	58	10	0	21	5	17	8	0	[illegible]	[illegible]6	19	4	0	30	13	1	7	0
		10.9	21.8	57.4	9.9	—	20.8	21.8	16.[illegible]	[illegible]9	—	21.8	[illegible]	18.0	1.8	—	29.7	12.6	0.8	6.9	—
4–6	66	8	17	32	9	0	12	18	29	7	0	13	32	16	[illegible]	0	16	26	23	1	0
		12.1	25.8	48.5	13.6	—	18.[illegible]	27.2	44.0	10.6	—	19.7	48.5	21.2	7.6	—	24.2	39.4	34.9	1.5	—
–10	57	5	10	37	5	0	7	13	8	9	0	10	27	1	4	1		24	23	[illegible]	0
		8.8	17.6	64.8	8.8	—	12.2	8	19.0	1.8	—	17.6	47.4	6.2	7.0	1.8	8.8	4[illegible].1	40.3	8.8	—
>10	68	9	24	26	9	0	15	24	22	7	0	14	28	19	5	2	1	27	22	6	1
		13.1	35.6	38.2	13.1	—	22.0	35.6	32.4	10.3	—	20.8	41.1	27.9	7.2	3.0	17.8	39.8	3.1	8.8	1.5
Total	292	33	73	153	33	0	55	80	126	31	0	59	143	[illegible]	18	3	63	120	89	19	1
		11.3	25.0	52.4	11.3	—	18.8	27.4	43.2	10.6	—	20.2	49.0	3[illegible]	6.2	1.0	21.6	41.1	30.5	6.5	0.3

Table 10 shows the di tribution of pain of various stages in the different duration groups Pain of stages 2—4 was pre ent in as many as 57 ankles (51 4 per cent) even in the first duration group

The percentage of painful joints was about the same in the next dura tion group Then a small increase was noted, and in the last group (over 10 years duration) a clear decre ise was ob erved Consequently, pain appears to be an early symptom which sets in at the same time as inflammation of the subtal ir joints

Range of motion

The range of motion of the TC joint was a es ed by different examiners and found to be as follows

No of ankles	Dorsiflexion			Plantar flexion		
	0 – 9	*10 – 15*	*>15*	*0 – 29*	*30 – 39*	*>40*
292	90	143	59	109	120	63
%	30 8	49 0	20 2	37 3	41 1	1 C

Limitation of motion occurred in dorsiflexion in 233 feet (79 8 per cent), *in plantar flexion in 229 feet (78 4 per cent) The figures show almo t com* plete agreement In only three feet in the whole series was no dorsiflexion observed and in one case of over seven years duration the joint showed no plantar flexion at all (stage 4) The largest group con i ts of feet with a dorsal flexion of 10—15 degrees and a plantar flexion of 30—39 degrees *Table 10 shows the increa e in the limitation of motion a sociated with pro* longation of the di ease As regards dorsiflexion a steady increase i ol erv- able but in reg ird to plantar flexion the limitation did not progress evenly The mo t steady progression was associated with stage 1

The decrea e in the range of motion as ociated with prolongation of the di ea e i consi tent with the decrease in swelling and pain

VI PREOPERATIVE RADIOLOGICAL FINDINGS

Previous investigations

STEINBROCKER, TRAEGER and BATTERMAN (1949) based their assessment of the stage of the disease on the functional capacity of the [illegible] and the roentgenological picture The various changes caused by the disease were classified into five stages FLETCHER and RAWLEY (1952) put forward the view that erosions are typical of rheumatoid arthritis and that [illegible] diological finding is pathognomonic of the disease although [illegible] not the first sign VAINIO (1956) mentioned narrowing of the [illegible] as an example of the radiological changes encountered in the [illegible] foot Narrowing of the TC joint space was thus observed in [illegible] per cent in his series Radiological changes of the talocal[illegible] cuboid and talonavicular joints occurred in 66 9 per cent [illegible] tween men and women was insignificant With prolong[illegible] the changes progressed in all joints Narrowing of the [illegible] far most frequently observed in the talonavicular joint [illegible] joint was quite clearly the one most often affected [illegible] erosions and osteophytes at the edges of the talocrural [illegible] late

SOILA (1958) mentioned that if inflammation [illegible] ankle bones may extend further so as to involve the [illegible] in calcium concentration is first discernible in the [illegible] fected joints SOILA only occasionally observed n[illegible] joint space while narrowing was very frequently [illegible] talocalcaneal calcaneocuboid and cuneonavicular [illegible] sions in the talocrural and subtalar joints were [illegible] ing and that it was typical of the erosions of the [illegible] localized at points where the weakened bone [illegible] the frontal projection of the ankle SOILA ob[illegible] osteal swelling in the contours of the tibia or f[illegible]

sals no periosteal swelling originating in the bone was seen According to SOILA arthrotic changes most often occur in the talonavicular joint while in other joints the changes are slight

In a series of 226 rheumatoid patients who had received protracted cortisone treatment GASCON and GRIGNON (1960) observed 26 pathological fractures and osteoporosis of degree III in 16 2 per cent of cases and of degree IV in 14 1 per cent (classification by I—IV)

SERRE SIMON GIVAUDAUD and BENA MARA (1962) assessed the radiological changes in the feet of 60 patients with RA using STEINBROCKER's et al (1949) classification and noted typical changes in 38 cases

According to ANSELL (1963) cyst like erosive changes in the malleoli may be regarded as early signs of RA in the ankle joints As time elapses calcium accumulates in these spaces giving an appearance resembling that of arthrosis She pointed out that narrowing of the joint space due to loss of articular cartilage in appositional areas may be the first sign of involvement of the ankle and tarsus particularly in the subtalar talonavicular and calcaneocuboid joints In some rheumatoid patients Ansell observed periosteal elevation and ossification along the outer aspect of the tibia, above the medial malleolus She found that secondary degenerative changes may supervene without obvious erosive changes having been visualized

In a study on 430 rheumatoid patient ISEMEIN and FOURNIER (1963) observed both clinical and radiological signs in the feet in 68 per cent Attention was mainly directed to the joints of the toes and to bony signs The articulation between the talus and scaphoid seemed to be severely affected

SOSMAN (1963) mentioned that according to his experience one of the common lesions of the foot is in the talonavicular joint, second only to the metatarsophalanges The talonavicular joint is also however a common site of osteoarthrosis SOSMAN pointed out that periostitis in the leg bones above the ankle does not always arise from rheumatoid arthritis and that carcinoma of the lung must be ruled out as a cause by the aid of chest radiograph

Present investigation

The subtalar joints

Osteoporosis

Table 11 shows the distribution of osteoporosis at various stages of development in different joints and duration groups The material (Op I) comprises a total of 284 feet Osteoporosis of stages 2—4 was observed round the talocalcaneal (tc) joint in 209 feet (73 6 per cent) round the calcaneocuboid (CC) joint in 257 feet (90 5 per cent) and round the talonavicular (TN) joint in 215 feet (75 8 per cent) A statistical analysis of the results is presented in Table 12 which shows that the development of osteoporosis as a function of time was linear and that the linear rise was highly significant as regards the talocalcaneal joint Round the talonavicular joint too osteoporosis showed an increase in severity which was significantly correlated with time On the other hand, in the area of the calcaneocuboid joint osteoporosis of stages 2—4 developed as quickly as within the first three years in 90 5 per cent of the feet and no significant progression emerged from comparison of the subsequent groups

Summary

Osteoporosis of the areas of the TN and tc joints was found to show a linear increase in severity with increasing duration of the disease This correlation was statistically significant

It seems possible that marked osteoporosis of the CC area develops in the early stage of R A although a deeper involvement may escape attention

Narrowing of the joint space

The material (group Op I) consists of 284 feet Narrowing of the joint space was observed as follows

Talocalcaneal	joint	251	feet	88 3	per cent
Calcaneocuboid	»	204	»	71 8	»
Talonavicular	»	235	»	82 7	»

When the occurrence of the severest stages (3 and 4) was separately analysed the following distribution emerged

Talocalcaneal	joint	86	feet	30 2	per cent
Calcaneocuboid	»	71	»	25 0	»
Talonavicular	»	168	»	59 1	»

TABLE 11 Preoperative osteoporosis of the triple joints in the different duration groups

Duration groups (years)	No. of feet	Talocalcaneal (TC) Stages 0	1	2	3	4	Calcaneocuboid (CC) Stages 0	1	2	3	4	Talonavicular (TN) Stages 0	1	2	3	4
<3	98	8	1	62	7	0	4	6	60	29	0	8	17	66	6	1
		8.[illegible]	1.1	[illegible]2	7	—	4.1	6.1	61.2	28.6	—	8.2	17.4	67.3	6.1	1.0
4–6	[illegible]	15	5	39	4	0	0	6	36	20	0	1	11	44	3	0
		12	8.6	61.7	6.4	—	—	9.7	58.0	3[illegible].3	—	1.6	[illegible]0	71.0	4.8	—
7–10	57	3	1[illegible]	36	3	0	1	4	46	6	0	2	13	39	3	0
		[illegible]	[illegible]8.7	63.1	5.2	—	1.8	7.0	80.7	10.[illegible]	—	3.5	2[illegible].8	68.5	5.2	—
>10	67	2	6	43	1[illegible]	1	1	5	37	23	1	1	13	38	12	3
		3.0	8.9	64.2	[illegible].4	1.[illegible]	1.5	7.4	5[illegible]	34.4	1.[illegible]	1.5	19.4	56.7	17.9	4.5
Total	8[illegible]	9	17	1[illegible]9	[illegible]9	1	6	21	1[illegible]	77	1	12	57	187	24	4
		[illegible]9	1[illegible]	63.0	10.[illegible]	0.4	1	7.4	63.0	[illegible]7.1	0.4	1[illegible]	[illegible]0.0	66.0	8.4	1.4

TABLE 1[illegible] *Analysis of statistical significance The frequency of preoperative osteoporosis in the region of the talocalcaneal calcaneocuboid and talonavicular joints in the different duration groups*

The talocalcaneal joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	1[illegible] 81	3	4 [illegible]	7 51	001
Linear	6 [illegible]	1	6 [illegible]	10 9[illegible]	001
Deviation	6 58	[illegible]	3 [illegible]3	[illegible]	01
Within	160 91	[illegible] 0	0 [illegible]7		
Total	1[illegible]3 [illegible]	[illegible]83			

M_1 = 1 6[illegible] M_2 = 1 50 M_3 = 1 6[illegible] M_4 = [illegible] 10

The calcaneocuboid joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	[illegible]	3	0 8[illegible]	[illegible] 0[illegible]	insignificant
Linear	0 1[illegible]	1	0 12	0 [illegible]	
Deviation	[illegible] 43	[illegible]	1 [illegible]	[illegible] 98	[illegible]
Within	116 00	[illegible]0	0 41		
Total	118 [illegible]	[illegible]3			

M_1 = [illegible] 14 M_2 = [illegible]3 M_3 = 2 00 M_4 = [illegible]7

The talonavicular joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	4 [illegible] 3	3	1 41	3 00	0[illegible]
Linear	[illegible]8	1	2 [illegible]8	[illegible] 91	0[illegible]
Deviation	1 4	[illegible]	0 [illegible]3	1 55	insignificant
Within	13[illegible] 3[illegible]	[illegible]0	0 4[illegible]		
Total	136 55	2[illegible]3			

M_1 = 1 [illegible] 4 M_2 = 1 [illegible]9 M_3 = 1 [illegible]5 M_4 = 2 04

TABLE 13 Preoperative narrowing of the joint space in the triple joints in the different duration groups

Duration groups (years)	No of feet	Talocalcaneal Stages					Calcaneocuboid Stages					Talonavicular Stages				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
<3	98	9	5	[illegible]	11	[illegible]	10	17	51	15	2	8	1	[illegible]	37	16
		[illegible]	[illegible]	61 2	19 4	[illegible]	10 2	17 3	55 1	15 3	[illegible]	8 2	[illegible]	[illegible]	37 8	16 3
1 6	62	[illegible]	1	11	13	0	7	11	[illegible]	13	1	3	8	8	[illegible]	8
	[illegible]	11 3	1 6	[illegible]	[illegible]	—	11 3	[illegible]	40 3	[illegible]	1 8	4 8	[illegible]	[illegible]	[illegible]	[illegible]
7 10	[illegible]7	1	4	[illegible]	19	4	7	12	[illegible]	11	3	3	7	11	2	11
		7 0	[illegible]	[illegible]	33 4	7 0	[illegible]	[illegible]	[illegible]	19 3	[illegible]	5 2	[illegible]	19 3	38 7	[illegible]
>10	[illegible]7	0	3	39	18	8	4	9	30	16	8	5	3	[illegible]3	17	19
		—	4 5	[illegible]	[illegible]	11 9	6 0	13 4	44 8	[illegible]	11 9	7 4	[illegible]	[illegible]	[illegible]	[illegible]
Total	84	0	13	[illegible]	[illegible]	17	8	[illegible]	133	[illegible]	16	19	30	67	111	[illegible]7
		7 1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18 3	16 8	[illegible]	[illegible]	6 7	10 6	[illegible]	39 1	[illegible]

TABLE 14 *Analysis of statistical significance The frequency of preoperative narrowing of the joint space in the talocalcaneal calcaneocuboid and talonavicular joints in the different duration groups*

The talocalcaneal joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	9 9[illegible]	3	3 31	4 41	01
Linear	[illegible] 60	1	7 60	10 13	01
Deviation	[illegible] 32	2	1 16	1 5[illegible]	insignificant
Within	[illegible]11 28	[illegible]0	0 [illegible]		
Total	2[illegible]1 [illegible]0	[illegible]83			

M_1 = [illegible] 06 M_2 = 1 97 M_3 = 2 [illegible]6 M_4 = [illegible] 46

The calcaneocuboid joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	[illegible] 85	3	[illegible] 62	2 6[illegible]	05
Linear	5 36	1	5 36	5 47	05
Deviation	2 49	2	1 [illegible]5	1 [illegible]8	insignificant
Within	[illegible]73 60	[illegible]80	0 98		
Total	[illegible]81 45	[illegible]83			

M_1 = 1 82 M_2 = 1 85 M_3 = 1 84 M_4 = 2 [illegible]2

The talonavicular joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	2 79	3	0 93	0 73	insignificant
Linear	2 08	1	[illegible] 08	1 64	"
Deviation	0 [illegible]1	2	0 36	0 28	"
Within	355 4[illegible]	280	1 27		
Total	358 [illegible]1	[illegible]83			

M_1 = [illegible] 42 M = 2 60 M_3 = 2 65 M_4 = 2 63

In the present study narrowing of the joint space was thus most often observed in the talocalcaneal joint and least often in the calcaneocuboid joint but the severest changes (stages 3 and 4) occurred by far most frequently in the talonavicular joint

Narrowing became more pronounced as the disease progressed In both the tc and the CC joints narrowing increased linearly as a function of time, and the correlation was statistically significant In the talocalcaneal joint the progression of the change showed even higher significance than in the calcaneocuboid joint (Table 14) On the other hand in regard of the talonavicular joint no significant correlation was found between the progression of joint space narrowing and the duration of the disease This shows that the change had already become established in the initial stage of the disease within three years The subsequent changes were statistically insignificant

Table 13 shows the distribution of the various stages of tc, CC and TN joint space narrowing in the different duration groups

The observation that narrowing of the TN joint space was an early sign is consistent with the finding that planovalgus developed during the initial stage of rheumatoid arthritis of the ankle It is noteworthy, moreover that in the over ten years duration group there were no more than eight cases (11 9 per cent) in which the tc joint space was so narrow that it could only be distinguished with difficulty in certain areas which means that at least fibrous anchylosis was present in the joint Likewise the CC joint space was very narrow (stage 4) in eight cases (11 9 per cent) The TN joint space was very narrow (stage 4) more than twice as often i e in 19 cases (28 3 per cent) This shows that anchylosis of the joints develops very slowly often over a period of ten years

Summary

In the present series narrowing of the joint space was most frequently observed in the talocalcaneal joint (88 3 per cent) and most seldom in the calcaneocuboid joint (71 8 per cent) Narrowing of the talonavicular joint space was found to be an early sign already established during the first three years

Narrowing of the talocalcaneal and calcaneocuboid joint spaces progressed linearly as a function of time and this correlation was statistically significant

Erosion

On examination of the preoperative radiographs of 284 feet the distribution of erosions in the tc CC and TN joints was found to be as follows

	No erosion (stages 0—1)		Erosion (stages 2—4)	
Talocalcaneal joint	158	55.6 per cent	126	44.4 per cent
Calcaneocuboid »	144	50.7 »	140	49.3 »
Talonavicular »	110	38.7 »	174	61.3 »

As is seen above, *erosion occurred most frequently in the TN joint* in which it was observed in 174 (61.3 per cent) of the 284 feet examined. In the calcaneocuboid joint this change was detected in 49.3 per cent of cases and in the talocalcaneal joint in 44.4 *per cent*. *The distribution of erosion* in the different duration groups is shown in Table 15. It appears that erosion increased in all three joints (tc, CC and TN) with increasing duration of the disease. Statistically the progression of erosion was highly significant as may be seen in Table 16. As demonstrated in Fig. 7 the destructive process most often began in the TN joint but during the course of the disease all three joints showed about the same steady deterioration.

Summary

Erosion occurred most frequently in the talonavicular joint in which it was observed in 61.3 per cent of the feet examined. In the calcaneocuboid joint this change was found in 49.3 per cent of cases and in the talocalcaneal joint in 44.4 per cent. The progression of erosion was found to be very closely correlated with the duration of the disease. Statistically the correlation was highly significant.

The periosteal reaction

Pure periostitis in which the periosteum is clearly thickened and elevated from the underlying cortical bone was not encountered round the subtalar joints. On the other hand at the edges of the joints and/or the cortical bone e.g. on the dorsal surface of the navicular, unevennesses in the form of osteophytes were observed.

Periosteal reaction was observed in the apices of the malleoli at the aspects opposite to the joints and correspondingly on both sides of the talu. Osteophytic spicules were often seen on the apices of the malleoli and on the anterior and posterior edges of the tibia. Very typical locations were the dorsal margins of the articulation between the navicular and talus and the calcaneocuboid joint in particular the lower margin of the cuboid and the posterior portion of the talus the posterior talar process. The distribution of the various stages of periosteal changes in the tc, CC and TN joints of the 284 feet examined was as follows.

Stage	tc	CC	TN
0	19	211	17
1	130	20	28
2	104	16	135
3	11	4	71
4	0	0	3
Stages 2—4	115	50	209
	40 5 %	17 6 %	73 6 %
Stages 1—4	245	70	237
	86 3 %	24 7 %	83 5 %

The clearly highest frequency of periosteal reactions (73 6 per cent) was observed in the area of the talonavicular joint If quite minimal changes (stage 1) i e a barely discernible unevenness of the surface are included the total number of affected TN joints was 237 (83 5 per cent) In the tc joint changes of this stage occurred somewhat more often i e in 245 cases (86 3 per cent) Periosteal marginal changes of the CC joint were relatively infrequent changes of stages 2—4 being observed in only 50 cases (17 6 per cent) In the region of the CC joint the periosteal changes mainly occurred at the lower edges of the joint The changes in the TN region were very often located in the dorsal margins of the joint and in the dorsal surface of the navicular often extending to the area of the cuneiform bone The talocalcaneal periosteal changes were found at the edges of the joint particularly in the processes e g the posterior talar process which significantly often became enlarged as the disease progressed Table 17 shows the development and increase of periosteal changes during the course of the disease The progression was most conspicuous in the TN region in which the differences between the various duration groups were statistically highly significant The differences in the tc region were also most significant and the exacerbation was found to be a linear function of time As may be seen in Table 18 and Fig 8 the progression of the changes was most linear in the TN joint

As the distribution of the changes in the CC joint was not suited for the χ^2 test the differences between the various duration groups were tested by variance analysis and the trend was tested by Jonckheere's non parametrical trend analysis The results obtained were as follows $\chi^2 = 8\,21$ (P < 05) and z = 2 78 (P < 01) Since the differences between the various duration groups were significant the conclusion may be drawn that the changes increased as the disease advanced

The statistical analysis of the periosteal changes in the tc and TN joints is shown in Table 18

TABLE 17 *Preoperative changes of the periosteal reaction in the triple joints in the different duration groups*

Duration groups (years)	No of feet	Talocalcaneal Stages					Calcaneocuboid Stages					Talonavicular Stages				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
<3	98	16 18.3	46 46.9	36 36.8	0 —	0 —	81 [illegible]	4 4.1	13 13.3	0 —	0 —	[illegible] [illegible]	14 14.3	17 18.0	[illegible] 15.3	0 —
4–6	62	14 [illegible]	27 43.6	19 30.6	2 [illegible]	0 —	19 79.0	[illegible] 8.1	8 [illegible]	0 —	0 —	11 17.7	3 4.8	31 [illegible]	11 [illegible]	0 —
7–10	57	5 8.7	22 38.7	[illegible] [illegible]	4 7.0	0 —	41 [illegible]	1 7.0	[illegible] [illegible]	[illegible] [illegible]	0 —	7 [illegible]	6 [illegible]	[illegible] [illegible]	19 [illegible]	1 1.8
>10	67	4 6.0	[illegible] [illegible]	[illegible] 31.4	[illegible] 7.4	0 —	43 61.2	7 10.4	16 [illegible]	1 [illegible]	0 —	7 10.4	[illegible] 7.4	30 44.8	[illegible] [illegible]	[illegible] 3.0
Total	[illegible]	39 13.7	130 45.8	104 36.7	11 3.8	0 —	[illegible] [illegible]	[illegible] [illegible]	16 [illegible]	4 1.4	0 —	47 [illegible]	[illegible] [illegible]	[illegible] [illegible]	71 [illegible]	3 1.1

TABLE 18 *Analysis of statistical significance The frequency of preoperative periosteal reaction in the talocalcaneal and talonavicular joints in the different duration groups*

The talocalcaneal joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	6.04	3	2.01	3.65	05
Linear	3.78	1	3.78	6.87	01
Deviation	2.26	2	1.13	2.05	Insignificant
Within	154.31	280	0.55		
Total	160.35	283			

$M_1 = 1.20$ $M_2 = 1.15$ $M_3 = 1.51$ $M_4 = 1.43$

The talonavicular joint

	Sum of Squares	Degrees of Freedom	Variance Estimate	F	Level of Significance
Between	14.67	3	4.69	4.91	01
Linear	14.23	1	14.23	14.37	001
Deviation	0.44	2	0.22	0.22	Insignificant
Within	277.20	280	0.99		
Total	291.87	283			

$M_1 = 1.56$ $M_2 = 1.82$ $M_3 = 2.02$ $M_4 = 2.12$

Summary

As regards the periosteal reaction, too the most obvious and most advanced signs of rheumatoid inflammation were discernible in the region of the talonavicular joint (in 73.6 per cent of cases) The slightest changes were observed in the calcaneocuboid joint (in 17.6 per cent) The changes in the talocalcaneal joint were clearly slighter than in the TN joint but when very slight changes were also taken into account the frequency of lesions was about the same in the TC and TN joints

Enlargement of the posterior talar process was another common finding in cases of old standing The conspicuousness of the erosive and reparative processes in the talonavicular region was a very typical feature This phenomenon could not be satisfactorily explained

Statistically the differences between the various duration groups were significant in regard of all three joints The changes showed a linear aggravation as a function of time This result too was significant The most vertical rise was observed in the TN region

Osteoarthrosis

Changes in the calcium concentration of the joints were noted. The right and left feet which were projected on the same X-ray film were always compared.

The distribution of osteoarthrosis in the tc, TN and CC joints of 284 feet was as follows:

Joint	*Stages 0–1*		*Stages 2–4*	
Talocalcaneal	188	66.2 %	96	33.8 %
Calcaneocuboid	247	87.0 %	37	13.0 %
Talonavicular	143	50.4 %	141	49.6 %

In the present material osteoarthrosis occurred most frequently in the TN joint, i.e. in 141 cases (49.6 per cent). The difference as compared with the other joints is considerable. In the tc joint arthrosis was observed in 96 cases (33.8 per cent), in the CC joint only in 37 cases (13.0 per cent). In the tc and CC joints osteoarthrosis showed gradual exacerbation with prolongation of the disease. In the TN joint the changes were slighter and the highest frequency was noted in the second duration group. Table 19 shows the development of arthrosis in the different joints in the various duration groups.

The differences between the duration groups were found to be highly significant in regard of the tc and CC joints and significant in regard of the TN joint. As may be seen in Table 19, in the tc and CC joints arthrosis clearly increased with prolongation of the disease. The most marked changes seemed to occur after six years. In the last group (duration over ten years) a slight fall was observed, which may be due to (fibrous) anchylosis. This fall seemed to be most marked in the TN joint, and it was discernible as early as six years from the onset. This observation seems to indicate that in the TN joint arthrosis develops in an early stage of the disease and later it may decrease.

Statistical analysis

The osteoarthrotic changes in the different duration groups were compared by variance analysis based on ordinal numbers and the trend was tested by non-parametric trend analysis.

Group Op I

Joint

tc $\chi^2 = 20.36$ $P < .001$ $z = 3.68$ $P < .001$ (highly significant)

CC $\chi^2 = 15.07$ $P < .001$ $z = 3.57$ $P < .001$ (highly significant)

TN $\chi^2 = 13.15$ $P < .01$ $z = 2.27$ $P < .05$ (significant)

TABLE 19 *Preoperative osteoarthrosis of the triple joints in the different duration groups*

Duration groups (years)	No. of feet	Talocalcaneal Stages					Calcaneocuboid Stages					Talonavicular Stages				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
3	98	[illegible]	21	17		0	88	5	5	0	0	52	10	21	15	0
		71	21.[illegible]	17.3	5.1	—	89.8	5.1	5.1	—	—	53.1	10.2	21.4	15.3	—
1–6	62	28	17	15	2	0	49	5	8	0	0	17	7	22	16	0
		45.2	27.4	24.2	3.2	—	79.0	8.1	12.9	—	—	27.4	11.3	35.5	25.8	—
7–10	57	10	20	1	6	0	38	7	11	1	0	15	10	18	14	0
		17.6	35.1	36.8	10.5	—	66.6	12.3	11.3	1.8	—	26.3	17.6	31.6	24.5	—
> 10	67	26	11	23	7	0	17	8	12	0	0	25	7	22	12	1
		38.8	16.4	34.4	10.4	—	70.2	11.9	17.9	—	—	37.4	10.4	32.8	17.9	1.5
Total	[illegible]	116	7[illegible]	76	20	0	[illegible]	2[illegible]	36	1	0	10[illegible]	31	83	57	1
		40.[illegible]	[illegible]	26.8	7.0	—	78.[illegible]	8.8	12.6	0.4	—	38.4	1[illegible].0	[illegible]	20.0	0.4

Summary

Osteoarthrotic changes were most clearly observed in the TN joint (in 49 6 per cent of cases) and most infrequently in the calcaneocuboid joint (in 13 0 per cent) The development of osteoarthrosis was gradual but as regards moderate or severe changes the various joints showed different patterns In the TN joint the maximum was observed in the duration group four to six years after which arthrosis decreased In the tc and CC joints the maximum occurred later i e between the seventh and tenth years After this arthrosis showed a gradual decrease The differences between the various duration groups were statistically significant as regards all joints (tc CC and TN) On comparison of the occurrence of osteoarthrosis and rheumatoid changes it was found that arthrosis was a less common sign in all joints (tc CC and TN)

Diagrams

In Figs 5—8 the arithmetical mean for the severity of the radiological changes is expressed on the ordinate while the duration of the disease in years calculated from the onset of symptoms in the foot until the time of operation is indicated on the abscissa

The diagrams show that erosion narrowing of the joint space and the periosteal reaction were throughout most marked in the TN joint and slightest in the CC joint although the differences became less pronounced in cases of long standing This applies in particular to narrowing of the joint space and erosion As regards osteoporosis the curves expressing the degree of severity of the radiological changes show a different pattern Throughout the severest changes were observed in the CC region and the slightest changes in the tc region although in this respect too the differences between the various joints decreased with increasing duration of the disease The curves show a gradual rise and the first and last duration groups differ most from each other The curves expressing osteoporosis have the least linear rise, which reflects the slightness of the differences between the duration groups Osteoporosis developed rapidly as the first sign of the disease, and subsequently showed little change

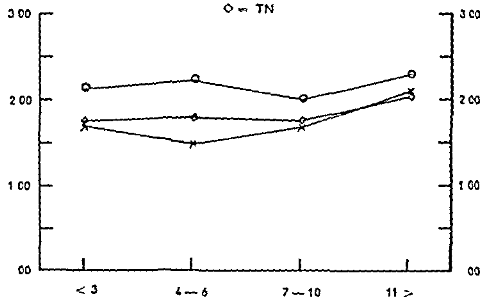

OSTEOPOROSIS
x = tc
o = CC
◇ = TN
3 00
2 00
1 00
00
< 3
4 — 6
7 — 10
11 >

Fig 5

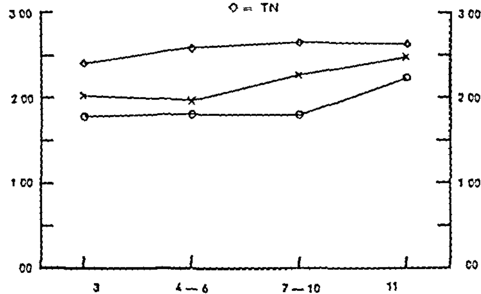

NARROWING OF JOINT SPACE
x = tc
o = CC
◇ = TN
3 00
2 00
1 00
00
3
4 — 6
7 — 10
11

Fig 6

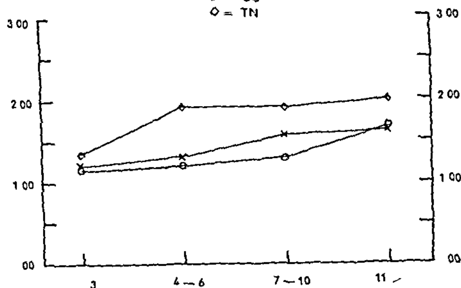


Fig 7

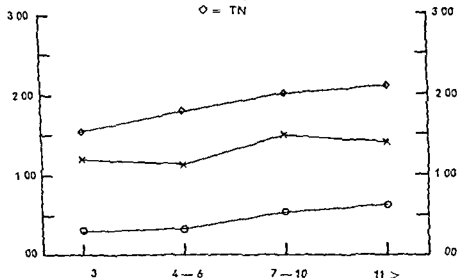


Fig 8

Figs 6 7 8 Radiological changes of various stages in the different duration groups comparison of the tc CC and TN joints The arithmetical mean for the severity of the changes is indicated on the ordinate the duration of the disease in years on the abscissa

The talocrural joint

The distribution of the findings in the groups Op I and Non-op I is shown in Tables 20 and 21

Osteoporosis of the TC joint was observed in the Op I group in 11 1 per cent of cases When the findings in the TC joint are compared with the corresponding findings in the tc, TN and CC joints, the difference is striking osteoporosis and narrowing of the joint space were observed in the latter in over 70 per cent of cases As regards osteoarthrosis, the value for the CC joint (13 0 per cent) is the only one that approximates to the corresponding value for the TC joint (12 7 per cent)

As may be seen in Table 21 the edges of the TC joint (the medial and lateral aspects of the malleolar part of the mortise) showed markedly more erosive changes than the mid part (the surface) of the joint The same phenomenon was also observed in the Non op I group On comparison of erosion in the subtalar joints and the TC joint the difference is obvious since even the region of the tc joint (in which this phenomenon was rare t) exhibited

TABLE 20 X ray changes in the talocrural joint

Group	No of ankles	Osteoporosis Stages 0–1	Osteoporosis Stages 2–4	Narrowing of the joint space Stages 0–1	Narrowing of the joint space Stages 2–4	Osteoarthrosis Stages 0–1	Osteoarthrosis Stages 2–4
Op I	[illegible]	[illegible]	[illegible]	211	40	[illegible]	[illegible]
		[illegible] 6 *	44 4	[illegible]	14 1	[illegible]	[illegible]
Non op I	[illegible]	[illegible]	69	[illegible]	[illegible]	183	[illegible]
		[illegible]	33 8	[illegible]	[illegible]	[illegible]	10.3 *

TABLE 21 Erosion in the talocrural joint

Group	No of ankles	Surface erosion Stages 0–1	Surface erosion Stages 2–4	Marginal erosion: Medial part of mortise Stages 0–1	Marginal erosion: Medial part of mortise Stages 2–4	Marginal erosion: Lateral part of mortise Stages 0–1	Marginal erosion: Lateral part of mortise Stages 2–4
Op I	[illegible]	[illegible]	[illegible]	[illegible]	96	194	[illegible]
		[illegible]	[illegible]	[illegible]	33 8	68.3	[illegible]
Non op I	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		84 3	[illegible]	[illegible]	24.5	[illegible]	[illegible]

ero ions in 41 1 per cent of cases It appears that all rheumatoid changes decrease in the proximal direction from the talocalcaneal joint

Tables 22 23 24 and 25 show the distribution of the radiological changes of the TC joint in the different duration groups In both the Op I and the Non op I group the distribution of osteoporosis was fairly even However in both groups (particularly the Non op I group) a definite decrease in osteoporo is occurred between the fourth and sixth years after which the change clearly progressed in both groups The values in the Op I group were consistently higher reflecting the progression of inflammation from the subtalar joints to the TC joint

Narrowing of the TC joint space clearly progre sed during the course of the disease in both the Op I and the Non-op I group As may be een in Table 24 and 25 the changes were slighter in all duration groups in the Non op I group

Ero ion of the TC joint too seemed obviously to progress with prolongation of the disease As appears in Table 25 the only exception is constituted by the malleolar mortise in the Non op I group duration group 4—6 years For some reason or other in this group a clear improvement was discernible in the otherwise steadily progressing course of the disease It seems pos ible that this error is due to the relative smallness of the duration groups in the Non op group In all duration groups the changes were invariably greater in the malleolar portion of the morti e than in the horizontal joint surface The differences between the lateral and medial aspects were slight in both groups examined The distribution was very even although changes seemed to be somewhat more frequent on the medial aspect in the Op I group at least The progression of arthrosis was obvious in both groups Initially it seemed to be very slow but in the over ten years duration group a considerable rise was noted in both the Op I and the Non op I group In addition the difference between the groups had diminished The same phenomenon was observable in respect of the other radiological changes surface erosion excepted which after ten years was al o clearly *more frequent in the Op I group*

Statistical analysis

Just as in testing osteoarthrosis of the subtalar joints variance analysis based on ordinal numbers was applied

The significance of the occurrence of erosion of the mortise of the TC joint was tested in the different duration groups

TABLE [illegible] *Preoperative X ray changes in the talocrural joint in the different duration groups*

Duration groups (years)	No of ankles	Osteoporosis Stages					Narrowing of the joint space Stages					Osteoarthrosis Stages				
		0	1	[illegible]	3	4	0	1	2	3	4	0	1	2	3	4
~3	19	3	30	31	2	0	81	6	5	3	0	90	1	3	1	0
		3 7	30 6	31 7	0	—	8[illegible] 7	6 1	5 1	3 1	—	91 8	1 1	3 1	1 0	—
4~6	[illegible]	19	[illegible]	16	0	0	[illegible]	1	3	1	0	50	6	5	1	0
		[illegible]	3 [illegible]	[illegible]8	0 7	—	83 [illegible]	6 5	1 8	1 8	—	80 [illegible]	0 7	8 1	1 6	—
[illegible] 10	57	1	11	[illegible]1	1	0	16	5	3	1	2	11	[illegible]	5	1	2
		0 3	1 6	1 1	[illegible]0	—	60 7	8 8	5 3	1 7	3 5	77 2	8 8	8 8	1 7	3 5
~10	67	1	1[illegible]	[illegible]9	10	1	30	8	6	9	5	11	8	12	5	1
		17 [illegible]	[illegible]1	13 3	14 9	1 [illegible]	[illegible]8 2	11 9	8 9	13 5	7 [illegible]	61 2	11 9	17 9	7 [illegible]	1 5
Total	[illegible]84	[illegible]7	81	103	[illegible]	1	[illegible]1	[illegible]3	17	16	7	[illegible]	[illegible]3	[illegible]	8	3
	[illegible]	[illegible]7 1	[illegible]	36 3	[illegible]8	0 3	77 8	8 1	[illegible]9	[illegible]	[illegible]6	7[illegible]	8 1	8 8	2 8	1 1

TABLE 23 *Preoperative erosive changes in the talocrural joint in the different duration groups*

Duration groups (years)	No of ankles	Surface erosion					Marginal erosion									
							Medial part of mortise					Lateral part of mortise				
		Stages					Stages					Stages				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
<3	98	66	20	8	4	0	13	26	26	3	0	50	23	22	3	0
	%	67.3	20.5	8.2	4.0	—	13.3	26.5	26.5	3.1	—	51.0	23.5	22.4	3.1	—
4–6	62	40	14	6	2	0	22	23	13	4	0	24	22	13	3	0
	%	64.5	22.6	9.7	3.2	—	35.5	37.1	21.0	6.4	—	38.7	35.5	21.0	4.8	—
7–10	57	33	13	7	3	1	26	11	16	4	0	23	16	15	3	0
	%	57.9	22.8	12.3	5.3	1.7	45.6	19.3	28.1	7.0	—	40.3	28.1	26.3	5.3	—
>10	67	24	15	20	7	1	25	12	24	6	0	25	11	23	8	0
		35.8	22.4	29.9	10.4	1.5	37.3	17.9	35.8	9.0	—	37.3	16.4	34.3	12.0	—
Total	284	163	62	41	16	2	116	72	79	17	0	122	72	73	17	0
	%	57.4	21.8	14.4	5.6	1.1	40.8	25.4	27.9	[illegible]	—	43.0	25.3	25.8	[illegible]	—

TABLE °1 X ray changes in the talocrural joint in the different duration groups of group Non op I

Duration groups (years)	No of feet	Osteoporosis Stages					Narrowing of the joint space Stages					Osteoarthrosis Stages				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
<1	33	19	4	9	1	0	32	1	0	0	0	31	1	1	0	0
	•	57 6	1 1	27 3	3 0	—	97 0	3 0	—	—	—	91 0	3 0	3 0	—	—
°–3	46	°6	10	10	0	0	45	1	0	0	0	46	0	0	0	0
		°6 6	21 7	°1 7	—	—	97 8	2 2	—	—	—	100 0	—	—	—	—
4–°	32	1.	16	4	0	0	30	0	1	1	0	°6	4	1	1	0
		37 5	°0 0	1° .	—	—	°3 8	—	3 1	3 1	—	81 3	12 5	3 1	3 1	—
°–10	41	13	13	13	.	0	34	3	0	4	0	31	6	0	4	0
		31 7	31 7	31 7	4 9	—	8° 9	7 3	—	9 8	—	7. 5	14 7	—	9 8	—
>10		9	13	.3	7	0	3.	°	°	8	3	3.	3	4	9	1
		17 4	4 9	41 2	13 .	—	67 3	.8	.8	1. 3	.8	67 °	5 8	7 6	17 4	1 9
Total	01	79	6	59	10	0	176	8	4	13	3	169	14	6	14	1
		°8 °	°° 5	8 9	4 3	—	8° °	3 9	1 9	6 4	1 5	8° 8	6 9	3 0	6 8	0 .

TABLE 25. X-ray changes in the talocrural joint in the different duration groups of group Non-op I

Duration groups (years)	No. of feet	Surface erosion Stages 0	1	2	3	4	Marginal erosion: Medial part of mortise Stages 0	1	2	3	4	Marginal erosion: Lateral part of mortise Stages 0	1	2	3	4
<1	33	5	8	0	0	0	7	[illegible]	1	0	0	27	6	0	0	0
	/	[illegible]8	[illegible]	—	—	—	81.8	1[illegible]	3.0		—	81.8	18.[illegible]	—	—	—
2–3	16	39	5	[illegible]	0	0	9		[illegible]	1	0	[illegible]	7	10	0	0
		81.8	10.9	4.[illegible]	—	—	[illegible]3.1	1[illegible]	1[illegible]		—	63.1	1[illegible]	[illegible]1.7	—	—
4–6	3	[illegible]1	8		1	0	11	10		1	0	0	[illegible]		1	0
		[illegible]6	5.0	6.3	3.1	—	[illegible]	31.[illegible]	6.3	3.1		6[illegible]5	8.1	6.3	3.1	—
7–10	[illegible]	[illegible]3	[illegible]	9	[illegible]	0	17	1	11	1	0	17	10	13	1	0
		[illegible]6.0	[illegible]0	19.[illegible]	[illegible]	—	11	[illegible]	6.[illegible]	[illegible]		11.[illegible]	1.4	31.7	[illegible]	—
>10	6	7	7	9	7		1	1	0	1	0	3	6	13	1	0
	[illegible]	51.[illegible]	13.[illegible]	17.3	13.[illegible]	3.8	16	7.[illegible]	18.6	7.[illegible]		[illegible]	11.6	36.[illegible]	7.6	—
Total	[illegible]01	13[illegible]	3[illegible]	1	[illegible]		116	38	13	7	0	116	38	14	6	0
		6[illegible]	18.[illegible]	10.3	1.1	1.0	[illegible]	18.[illegible]	1.1	3.1	—	6[illegible]	18.6	[illegible]	[illegible]	—

Group Op I

Surface erosion of the TC joint

$\chi^2 = 23.66$ $P < .001$ $z = 1.3.$ $P < .001$ (highly significant)

The medial part of the mortise

$\chi^2 = 2.89$ $P > .05$ $z = 1.18$ $P > .05$ (*insignificant*)

The lateral part of the mortise

$\chi^2 = 7.02$ $P > .05$ $z = 2.63$ $P < .01$ (most significant)

As regards the development of erosion of the horizontal joint surface the differences between the various duration groups are highly significant. As may be seen in Table 23, the trend of the progression is clearly the same in all duration groups.

The differences between the duration groups are insignificant in regard of erosion of the medial aspect of the mortise but most significant in regard of its lateral aspect. In other words as far as the medial surface of the mortise is concerned, there was no significant difference even between the first duration group representing the initial stage of the disease, and the later groups. Erosive changes in this part are an early sign, and the changes subsequently developing do not attain statistical significance. However a definite difference was observed between the first and last duration groups (Table 23). In cases of old standing erosion seems to increase.

On comparison of the Non-op I and Op I groups the following results were obtained (the U test).

Surface erosion of the TC joint

$z = 1.91$ $P < .05$ (significant)

The medial part of the mortise

$z = 3.30$ $P < .001$ (highly significant)

The lateral part of the mortise

$z = 2.87$ $P < .01$ (most significant)

The statistical analysis shows that erosions were more frequent in the Op I group than in the Non-op I group. The differences are significant in particular as regards the malleolar mortise which showed clearly more erosions in the Op I group.

Summary

In the group of ankles on which operation was to be performed (Op I) the TC joint showed osteoporosis in 44.4 per cent of cases, narrowing of the joint

space in 14 1 per cent surface erosion in 20 8 per cent erosion of the medial part of the mortise in 33 8 per cent erosion of the lateral part of the mortise in 31 7 per cent and osteoarthrosis in 12 7 per cent Osteoporosis was thus the most frequent sign In the conservatively treated group (Non op I) the pattern of distribution was the same although the frequency figures were definitely lower The changes progressed during the course of the disease (Tables 20—21 22—23 and 24—25)

The only exception was constituted by the erosive changes of the medial aspect of the mortise which developed within three years and showed no appreciable advance the subsequent changes being statistically insignificant

Group Op I

Surface erosion of the TC joint

$\chi^2 = 23.66$ $P < .001$ $z = 1.75$ $P < .001$ (highly significant)

The medial part of the mortise

$\chi^2 = 2.89$ $P > .05$ $z = 1.48$ $P > .05$ (insignificant)

The lateral part of the mortise

$\chi^2 = 7.02$ $P > .05$ $z = 2.63$ $P < .01$ (most significant)

As regards the development of erosion of the horizontal joint surface, the differences between the various duration groups are highly significant As may be seen in Table 23 the trend of the progression is clearly the same in all duration groups

The differences between the duration groups are insignificant in regard of erosion of the medial aspect of the mortise, but most significant in regard of its lateral aspect In other words, as far as the medial surface of the mortise is concerned there was no significant difference even between the first duration group representing the initial stage of the disease, and the later groups Erosive changes in this part are an early sign and the changes subsequently developing do not attain statistical significance However, a definite difference was observed between the first and last duration groups (Table 23) In cases of old standing erosion seems to increase

On comparison of the Non-op I and Op I groups the following results were obtained (the U test)

Surface erosion of the TC joint

$z = 1.91$ $P < .05$ (significant)

The medial part of the mortise

$z = 3.30$ $P < .001$ (highly significant)

The lateral part of the mortise

$z = 2.87$ $P < .01$ (most significant)

The statistical analysis shows that erosions were more frequent in the Op I group than in the Non op I group The differences are significant, in particular as regards the malleolar mortise, which showed clearly more erosions in the Op I group

Summary

In the group of ankles on which operation was to be performed (Op I) the TC joint showed osteoporosis in 44.4 per cent of cases narrowing of the joint

Patients were formerly hospitalized in a very late stage when marked radiological changes of the subtalar joints had already developed. During the last few years the presence of such changes has not been regarded as conditional; pain on weight bearing has been a decisive indication for subtalar arthrodesis in cases in which the patient has been unable to manage with the aid of supports. The development of severe deformities which may jeopardize the results of operation has thus been avoided at the same time.

If the changes in the talocrural joint have been slight, only triple arthrodesis has been performed. In the presence of marked destructive changes in the TC joint, total (pantalar) arthrodesis has been carried out simultaneously.

Deformity causing discomfort has also been regarded as an indication for triple arthrodesis unless the patient has adapted himself to the situation.

The following factors have been regarded as possible contra-indications to operation: General disease with severe multiple deformities. Lack of [illegible] operation, because a better end result is obtained when the patient himself wants the operation and has a positive attitude to it. Severe amyloidosis. The presence of cardiovascular, respiratory and other complicating diseases and old age with severe general disease have been regarded as [illegible] contra-indications. On the other hand, elevated erythrocyte sedimentation rate and cortisone treatment have not been regarded as contra-indications.

Technical considerations of triple arthrodesis

Subtalar (triple) arthrodesis, with which this study is concerned [illegible] the talocalcaneal, talonavicular and calcaneocuboid joints. [illegible] every case a cortical bone graft was applied between the [illegible] neus in the sinus tarsi (GRICE's original method (1952) [illegible] articular arthrodesis was performed by the aid of [illegible] grafts obtained from the proximal part of the tibia [illegible] by VAINIO (1958) for rheumatoid cases. This modification [illegible] CAMPBELL's technique (e.g. the fourth edition of Campbell's [illegible] Orthopaedics 1963).

With the patient supine on the operating table, the different [illegible] formed in the following order:

1. After the tarsal sinus was emptied of its contents, the [illegible] opened after incision of its capsule, and the cartilaginous [illegible] away. The synovial tissue and pannus were also removed. [illegible]

2. The same procedures were carried out on the [illegible] surfaces were modelled so as to give a good contact with [illegible]

3 The cartilage was chiselled off the anterior articular process of the calcaneus the anterior aspect of the talus the articular surfaces of the *sustentaculum tali* and the anterior part of the posterior facet of the talus The articular surfaces of the talocalcaneal joint were removed and appropriate bony wedges were chiselled off to ensure good correction of any possible malposition

4 As the first reconstructive step the foot was displaced so that the debrided articular surfaces were in the best possible contact with each other and in midposition or slight valgus Varus position is inappropriate Special attention was given to the position of the forefoot which was also placed in midposition

The calcaneocuboid joint was fixed by means of a staple (stainless steel)

5 A cortical bone graft including good spongy tissue was applied between the talus and calcaneus in the sinus tarsi in which an appropriate groove was modelled by removing a small amount of bone tissue from the surface of both the talus and the calcaneus The graft was modelled into appropriate shape and set firmly into its groove with the cortical side outwards perpendicularly against the direction of movement of the subtalar joint The spaces between the fused joints were filled with bone grafts (chips) from the portions of removed bone (if this could be used) and from the graft to be applied The sinus tarsi too was packed full of chips round the graft as described by Vainio (1958)

The graft was taken from the iliac crest just before being used It measured about 2—3 cm (one inch) in length 1—2 cm (about half an inch) in breadth and about 0.5—1 cm in thickness counted from the cortical aspect It was shaped into a wedge in such a way that the sharp spongy aspect would become better fixed into the groove that was modelled in the sinus tarsi

6 A below knee well moulded plaster cast was applied while the patient was still lying on the operating table and the surgeon was holding the foot which he moved to the correct position and placed in alignment with the longitudinal axis of the leg

About 14 days after operation the cast and the stitches were removed and a new plaster cast was applied This occasion offered an opportunity of correcting any slight deformities by remodelling One or two days later a heel was applied under the cast and partial weight bearing was allowed at first with crutches or with a cane The patient was encouraged to walk freely if this did not increase the pain The duration of immobilization was eight weeks from operation after which the cast was removed and the ankle was bound up with an elastic bandage

Exercise of the ankle joint was immediately started and supports were modelled

In the majority of cases (218) the operation was carried out under general anaesthesia Spinal anaesthesia was employed only twice owing to the risk of shock which is particularly great in rheumatoid patients Many of the patients had been on cortisone therapy and were therefore given cortisone routinely on the evening preceding operation and after the operation During the last few years covered by this study block anaesthesia has become more widely used Combined sciatic-femoral-cutaneus femoris lateralis nerve block was used in 30 cases as described by Moore (1953 1962) and Vainio, Sarvas (1961) No complications from anaesthesia occurred one

case perhaps excepted, in which postoperative *bronchitis bronchiolitis* developed, obviously due to vomiting caused by the ether

Other procedures carried out in connection with triple arthrodesis

1) In four cases varus of the forefoot (sometimes associated with cavus) was corrected by cuneiform osteotomy in the area of the first cuneo metatarsal joint Owing to the fixation of the deformity soft tissue operations were excluded At the same time elevation of the first metatarsus was corrected as suggested by VAINIO (1950)

2) Resection of the proximal phalanx of the great toe was performed twice on account of hallux rigidus In these cases the resected bone was used as graft in triple arthrodesis

In one case partial resection of the proximal phalanges of the second to fifth toes was carried out on account of severe digitus malleu

3) In one case the Achilles tendon was elongated because of tension and slight varus In another case the anterior tibial tendon was elongated on account of varus of the forefoot

4) In one case severe medial exostosis was removed from the os naviculare

As a rule no other operations were performed in association with triple arthrodesis If the foot to be operated upon showed severe digitus malleus deformities these were usually first corrected or they were corrected later By the time of the follow up examination operations of resection type had been *performed on a total of* 76 feet (26 0 per cent) *on account of* hallux valgus or digitus malleus Only the severest and most painful deformities of the toes were operatively treated

Postoperative rise in temperature and ESR values

The *preoperative mean temperature ranged from* 36 0 to 37 5 The postoperative temperature charts of 267 cases were studied In 38 of these cases *no definite rise in temperature was observed even on the first few days* after operation In evaluating elevation of temperature 37 0 or the preoperative possibly higher level was taken as the basis The mean rise was 0 5 , and the postoperative temperature ranged from 37 0 to 39 0 The rise exceeded 1 0 only in 23 cases The temperature dropped to the preoperative level within a week Almost all of the present patients had regularly been receiving drugs of the chloroquine type or pain relieving drugs (and often also cortisone preparations)

3 The cartilage was chiselled off the anterior articular process of the calcaneus the anterior aspect of the talus the articular surfaces of the sustentaculum tali and the anterior part of the posterior facet of the talus The articular surfaces of the talocalcaneal joint were removed and appropriate bony wedges were chiselled off to ensure good correction of any possible malposition

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Histological findings

Tissue specimens from a total of 112 feet were patho-anatomi [illegible]. The specimens were mostly taken from synovial ti [illegible] to the area of the tarsal sinus or from the hyperpla tic synovial t [illegible] joint. From 150 feet no tis ue specimens were remitte [illegible]. Among the 112 specimens examined [illegible] (86.6 per cent) [illegible] typical of rheumatoid arthritis. In 93 ca es ([illegible] per cent) [illegible] even typical of very active inflammation and in [illegible] they were typical of chronic rheumatoid arthritis. Only [illegible] per cent) were too unspecific in character to warrant a [illegible]

In the above mentioned 112 feet the serological re [illegible] 81.6 per cent of cases (very clearly positive in 27 [illegible] in only [illegible] per cent. Thus there seemed to be a fa [illegible] between positive serological results and the histolo [illegible] 86.6 per cent of the cases examined showed changes [illegible]

VIII FOLLOW-UP STUDIES

Previous investigations

All previous follow up studies have been performed on series in which subtalar or triple arthrodesis were carried out for reasons other than rheumatoid arthritis, chiefly residual paralysis, especially sequelae of poliomyelitis. *No follow up study of RA as an indication for triple arthrodesis has hitherto been published.*

In HOKE's (1921) series of 104 operations, only 57 cases were followed up. The results were good in 98.2 per cent and poor in 1.2 per cent.

The most extensive series is that described by SMITH and VON LACKUM (1925). It comprised 223 patients on whom triple arthrodesis was performed. Follow up results were reported in 155 cases as follows: good in 66.1 per cent, fair in 23.7 per cent, poor in 6.9 per cent.

GILL (1927) reported 60 cases of triple arthrodesis which were all followed up. The results were good in 73.3 per cent and poor in 26.7 per cent.

HALLGRIMSSON's (1943) series comprised 100 operations, i.e. 68 triple arthrodeses and 32 operations performed by HOKE's method. All these cases were followed up. The results were good in 69 per cent, fair in 24 per cent, poor in 6 per cent, and one patient had become worse. Pseudarthrosis was observed in 15 cases in the TN joint, which was more frequently than in the TC and CC joints.

PATTERSON, PARRISH and HATHAWAY (1950) reported a series of 295 feet on which arthrodesis was performed, including 89 cases of triple (RYERSON) arthrodesis. The indications consisted of poliomyelitis and other paralytic deformities, cerebral palsy, etc. One patient had rheumatoid arthritis. Weight bearing was allowed after four to six weeks and total plaster immobilization was maintained for a maximum of twelve weeks. In the 89 cases of triple arthrodesis the results were good in 48 (53.9 per cent), fair in 27 (30.4 per cent) and poor in 14 (15.7 per cent). Pseudarthrosis occurred most frequently in the TN joint, i.e. in 12 cases.

ALLDREDGE and RIORDAN (1953) performed triple arthrodesis in 63 cases, of which only 22 were followed up. They used staple and clips in each joint (three staples in each case) if possible. *No complications occurred*, but in two cases a staple had to be removed because it had risen under the skin and caused discomfort. *No occurrence of corrosion was reported.*

GRICE (1955) described 52 cases in which he used two cortical grafts obtained from the tibia which he applied extra-articularly between the *calcaneus and the talus. The series comprised only juvenile* planovalgus feet but Grice pointed out that the method could also be applied in adults if *triple arthrodesis was simultaneously performed*. He reported good fusion of the graft within eight to ten weeks. Partial weight-bearing was allowed nine to eleven weeks after operation. The series comprised only three *failures*.

VAINIO (1956) performed triple arthrodesis on 27 feet and reported good results.

In his paper »Surgery in rheumatoid arthritis« HARRIS (1956) described various operative techniques. He had used arthrodesis only in the treatment *of weight bearing* joints and he had performed this operation on six knees and three feet. The results were highly satisfactory in all cases.

GRICE's method was used by WESTIN and HALL (1957) in 62 cases in the treatment of flat foot and other deformities (due to paralysis or other causes) in children. The authors pointed out that marked valgus affects the *talocrural* mortise causing talar tilting.

ROBINS (1959) published a follow up study on 60 polio patients on whom triple arthrodesis had been performed. The period of observation was at least ten years in all cases. At the end of the follow up period Robins observed rounding of the edges of the talus. Only slight limitation of the range of motion of the talocrural joint was noted. Degenerative changes did not occur provided that the valgus or varus deformities had been adequately corrected. Compensatory tilting of the lateral aspect of the talus was not associated with clinical instability or pain.

LINDHOLM (1960) published the follow up results of 211 operations, i.e. 16 triple arthrodeses, 173 triple arthrodeses combined with tendon transfer and 22 arthrodeses performed by LAMBRINUDI's method. The patients showed improvement in 67.8 per cent of cases, while 21.3 per cent were unaltered and 10.9 per cent were worse than before operation.

In a series of 42 paralytic valgus feet on which extra-articular triple arthrodesis was performed by GRICE's method, INGELRANS (1962) observed increased instability of the ankle.

CLAYTON (1963) stated that triple arthrodesis was indicated in the presence of subtalar changes in an otherwise well preserved ankle joint and provided that the patient experienced pain and showed valgus deformity.

HOWLAND (1964) performed triple arthrodesis on 129 patients with club foot, polio, spina bifida, spastic cerebral palsy, etc. In the majority of cases (102) he used RYERSON's method. LAMBRINUDI's method was used in 13 cases, HOKE's in 10, and other techniques in two cases. Pseudarthrosis resulted in 19 cases, in 7[illegible] per cent of these in the TN joint, but mostly no subjective symptoms were caused. Staples were used in 26 cases. The mean duration of plaster immobilization was eleven weeks. Complete failure was noted in 6 cases. The author recommended midline or slight valgus positioning of the calcaneus. Arthrosis of the TC joint was observed at follow up in one case.

POLLOCK and CARRELL (1964) treated 112 cases of paralytic valgus deformities by subtalar extra-articular arthrodesis. The results were unsatisfactory in 37.5 per cent.

HUCKSTEP (1964) utilized extra-articular subtalar arthrodesis as described by GRICE in the treatment of flat foot in 37 children. The range of motion of the TC and Chopart's joints remained the same, and no instability was observed, nor arthrosis of the TC joint. The results were satisfactory in 78 per cent of cases.

KIVILAAKSO, LANGENSKIÖLD and SALENIUS (1965) described a series comprising 32 patients on whom triple arthrodesis was performed for post-traumatic conditions. Weight bearing was begun one month after operation and the longest duration of plaster immobilization was four months. The result was good in 26 cases, while pain persisted in 6. One pseudarthrosis of the Chopart joint was observed.

The most extensive series of triple arthrodeses described is that of WILSON, LAMOTTE and WILLIAMS (1965). They performed the operation in 301 cases, mostly by RYERSON's and HOKE's methods. The age of the patients ranged from [illegible] to 60 years, the mean operative age being 12 years. The mean follow up period was [illegible]8 years. The indications for operation were 1) polio, 2) congenital deformities, 3) severe flat foot, 4) pain resulting from subtalar or midtarsal arthritis of any origin.

In recent years staples were used in the CC joint in 60 feet and in combination with some other device (e.g. graft, nail) in 38 feet. Weight bearing in plaster was begun at two to 16 weeks after operation, the average being 7.1 weeks. Pseudarthrosis was found in 31 cases (10.3 per cent) in the whole series, the site in [illegible] per cent of these cases being the talonavicular joint. The development of pseudarthrosis was obviously due to early

absence of bony contact in the talonavicular joint Superficial infection was observed in 61 cases According to the authors the development of pseudarthrosis was not influenced by the duration of immobilization in plaster but it was influenced by too early weight bearing

Present investigation

A total of 290 operatively treated (Table 26) and 191 conservatively treated feet were clinically examined During the interval between operation and the time of the follow up study five patients had died On two of these triple arthrodesis had been performed bilaterally However clinical data were lacking only in the case of two operatively treated feet i e two patients who had never visited the hospital after operation

The author himself examined 255 of these feet The remaining 35 feet were examined by other doctors on the hospital staff or follow up examination was made immediately after removal of the plaster cast In these 35 cases the clinical data were checked by the aid of questionnaires

A complete radiological study was performed on 218 operatively treated and 170 non operatively treated feet Radiological stress investigation were performed by the author on 255 triple arthrodesis feet and 200 non operatively treated ankles

The mean follow up period was 3 7 years Of the examined feet that had been operated upon 80 (27 5 per cent) belonged to men i e 41 left and 39

TABLE 26 *Interval (in years) between operation and follow-up examination in 290 cases of triple arthrodesis*

Sex	L/R	<1	2–3	4–6	>7	No of feet
Male	L	9	17	8	7	41
	R	8	15	5	11	39
No of feet		17	3	13	18	80
		21 2	40 0	16 3	22 5	27
Female	L	7	51	14	23	98
	R	9	60	21	22	112
No of feet		16	114	35	45	210
		7 6	54 0	17 1	21 3	72 5
Total no		33	116	48	63	290
%		11 4	50 4	16 5	21 7	100 0

right feet The female feet numbered 210 (72 5 per cent), i e 98 left and 112 right feet Table 26 shows the distribution according to duration (in years from operation) The interval between operation and follow up was over seven years in 63 cases (21 7 per cent) and less than a year in 33 cases (11 4 per cent) In the largest group consisting of 146 feet (50 4 per cent) two to three years had elapsed since operation

Clinical findings

The subtalar joints

Swelling pain and range of motion

Swelling was observed in 63 feet (21 7 per cent) in the Op II group and in 109 feet (56 2 per cent) in the Non-op II group As swelling was present before operation in 287 feet (98.3 per cent) the difference is considerable Moderate or marked pain at rest also showed a clear decrease, being present before operation in 182 feet (62 3 per cent) and at follow up in only 10 feet (3 4 per cent)

In the Op II group pain at rest occurred as follows

Stage 0	143 feet	49.3 per cent
Stage 1	137 »	47 3 »
Stage 2—4	10 »	3 4 »
Total	290 »	100 0 »

In association with follow up of the operatively treated feet, pain on stress (weight bearing), but not on motion, as mobility was lost in all cases, had clearly decreased after operation The distribution at follow up was as follows

Stage 0	226 feet	78 0 per cent
Stage 1	52 »	17 9 »
Stage 2	10 »	3 4 »
Stage 3	2 »	0 7 »
Stage 4	0 »	0 »

Before operation pain of stages 2—4 was present in 288 feet (98 6 per cent) postoperatively in only 12 feet (4 1 per cent) In the non operatively treated feet pain was present at follow up in 42 2 per cent of 194 (Table 27) Pain was thus a common symptom in this group of feet also

In the feet operated upon, no subtalar motion was observed The joints showed either bony or fibrous anchylosis In the conservatively treated group a definite decrease in the range of motion was observed at follow up

TABLE 27 *Swelling, pain on motion and range of movement (Groups Op II and Non-op II)*

Group	No. of feet	Swelling Stages 0–1	Swelling Stages 2–4	Pain on motion Stages 0–1	Pain on motion Stages 2–4	Range of movement Stages 0–1	Range of movement Stages 2–4
Op II	290	227	63	278	12	290	0
	%	78.3	21.7	95.9	4.1	100	–
Non-op II	194	85	109	112	82	53	141
		43.8	56.2	57.8	42.2	27.4	72.6

TABLE 28 *Occurrence of planovalgus*

Group	No. of feet	Stages 0–1 <10		Stage 2 11–15		Stage 3 16–20		Stage 4 >20	
Op I	292	37	12.6	127	43.5 *	93	31.8 *	35	12.0
Op II	290	31	10.7	193	66.5	53	18.3	13	4.5 *
Non-op I	204	41	20.1 *	120	58.8	31	15.2	12	5.9
Non-op II	194	32	16.6	111	57.2	40	20.6	11	5.6

TABLE 29 *Occurrence of deformities other than planovalgus*

Group	No. of feet	Deformity	Stages 0–1	Stage 2	Stage 3	Stage 4
Op II	290	Calcaneovarus	273	12	4	1
			94.1	4.1	1.4	0.4
Op I	292	Calcaneovarus	265	15	12	0
			90.8	5.1	4.1	–
Op II	290	Varus of the forefoot	240	38	12	0
			82.8	13.1	4.1 *	–
Op I	292	Varus of the forefoot	235	37	19	1
			80.6	12.6	6.5	0.3
Op II	290	Cavus or calcaneocavus	270	16	4	0
			93.1	5.5	1.4	–
Op I	292	Cavus or calcaneocavus	272	16	4	0
			93.1	5.5	1.4	–

in 141 feet (72 6 per cent) which shows that inflammation was of common occurrence although in many cases it was in a relatively inactive stage at the time of the follow up examination

Deformities

The distribution of *planovalgus* at follow up in the operatively and non operatively treated feet (groups Op II and Non op II) is shown in Table 25 For the sake of comparison the distribution before operation (group Op I) and at the same point of time in the conservatively treated feet (group Non op I) also appears in the table

The greatest differences in planovalgus are found between the group *Op I and Op II The severest stages (3 and 4) have markedly decreased after* operation Correspondingly stage 2 (valgus of 11—15 degrees) shows an increase from 127 feet (13 6 per cent) to 193 feet (66 5 per cent) Planovalgus of stage 3 was present at follow up in 53 feet (18 3 per cent) and stage 4 (the severest stage) in 13 feet (4 5 per cent)

The conservatively treated feet had remained largely as before except that stage 3 shows a slight increase in frequency This reflects the development of the deformity into rigidity after which no major changes are possible

In performing triple arthrodesis an attempt was made to place the calcaneus into slight valgus position The severest deformities clearly decreased but valgus of 11—15 degrees showed a marked rise

The distribution of other deformities in the feet operated upon is shown in Table 23

Calcaneovarus was still present in 17 feet (5 9 per cent) varus of the forefoot in 50 feet (17 2 per cent) and cavus or calcaneocavus in 20 feet (6 9 per cent) i e the same as before operation

Calcaneovarus was in every case associated with pes planus, and in 10 cases with varus of the forefoot In the remainder of cases varus of the forefoot was associated with planovalgus

Calcaneovarus (27 feet) showed a clear decrease but nonetheless this deformity was still present in 17 feet Varus of the forefoot had also decreased as far as the severest forms were concerned but milder degrees were still encountered in 50 feet

The calcaneocavus and cavus deformities were relatively slight and caused no discomfort Calcaneovarus on the other hand causes discomfort on walking Varus of the forefoot too impedes walking particularly in association with calcaneovarus pes varus

Evaluation of the results (Tables 30 and 31) When deformities of stages 3—4 persisted the result is evaluated as poor Stage 2 is regarded as a fair result and stages 0—1 as good However planovalgus up to 15 degrees (stages 0—2) is regarded as good stage 3 as fair, and stage 4 as poor

If planovalgus of stage 2 were regarded only as fair only 31 feet (10.7 per cent) would show good results while the results would be fair in 246 feet (84.8 per cent) and poor in 13 (4.5 per cent)

In the group with poor results the above mentioned deformities were more pronounced except in five feet in which calcaneovarus was associated with marked varus of the forefoot (pes varus) In the »fair» group the deformities were also obvious and responsible for the fact that the foot was not anatomically quite good From this group however must be subtracted the above mentioned five feet which showed pes varus and therefore were poor results The final objective anatomical results are shown in Table 31

This classification of the results presupposes that calcaneovalgus of 15 degree or less is regarded as good when it is not associated with other deformities In that case the functional capacity of the foot is determined by the associated deformities mainly by the degree of varus

Summary

Pain on stress was present in only 12 feet (4.1 per cent), definite swelling in 63 feet (21.7 per cent) Not all anatomically poor feet caused persistent pain When evaluated from the standpoint of the anatomy of the foot the results are not

TABLE 30 *Results of the correction of various deformities*

Deformity	Good		Fair		Poor	
Planovalgus	224	77.2	53	18.3	13	4.5
Calcaneovarus	273	94.1	12	4.1	5	1.8
Varus of the forefoot	240	82.8	38	13.1	12	4.1
Cavus or calcaneocavus	270	93.1	16	5.5	4	1.4

TABLE 31 *Final objective anatomical results*

Good	142	feet	48.9
Fair	114	feet	39.3 *
Poor	34	feet	11.8
Total	290	feet	100.0

*

TABLE 32 *Clinical findings in the talocrural joint*

Group	No of ankles	Swelling Stages 0–1	Swelling Stages 2–4	Pain on motion Stages 0–1	Pain on motion Stages 2–4	Dorsiflexion Stages 0–1	Dorsiflexion Stages 2–4	Plantar flexion Stages 0–1	Plantar flexion Stages 2–4
Op I	[illegible]	106	18[illegible]	13[illegible]	15[illegible]	20[illegible]	90	183	10[illegible]
		36 3	63 [illegible]	46 [illegible]	53 8	69 [illegible]	30 8	62 7	3[illegible] 3
Op II	[illegible]90	19	71	[illegible]	48	165	105	153	13[illegible]
		[illegible]	[illegible]4 1	83 [illegible]	16 [illegible]	61 8	36 [illegible]	[illegible]8	4[illegible]

equally favourable Only 31 feet (10 7 per cent) showed valgus up to 10 degrees and 246 feet (84 8 per cent) showed valgus of 11—20 degrees In other words rather marked planovalgus of the foot was still observed in a large proportion of the patients

The talocrural joint

Swelling pain and range of motion

In Table 32 the observations made at follow up examination are compared to the preoperative findings

Swelling showed a definite decrease In other words the swelling present before operation was largely due to inflammation of the subtalar joints Moderate or severe swelling was still present in 71 joints (24 1 per cent) The corresponding figure for the region of the subtalar joints was 63 (21 7 per cent)

Pain was present in 48 ankles (16 5 per cent) a clear decrease which reflects the improvement in the situation after operation However slight pain and tenderness on palpation was still observed in the area of the ligaments and at the corners of the joint in 162 ankles (55 9 per cent) Thus the number of completely painless (stage 0) ankles was only 80 (27 6 per cent)

The range of motion had clearly decreased at the follow up examination as compared with the situation before triple arthrodesis was performed This applies in a slightly higher degree to plantar flexion than to dorsiflexion Dorsiflexion was limited to less than 10 degrees in 105 ankles (36 2 per cent) and plantar flexion to less than 30 degrees in 137 ankles (47 2 per cent) Dorsiflexion regarded as normal (stage 0) was present in 72 ankles (24 8 per cent) and plantar flexion in 58 ankles (20 0 per cent)

Radiological findings

The subtalar joints

Osteoporosis

In Table 33 the occurrence of osteoporosis after operation (group Op II) is compared with the values noted preoperatively (group Op I). The table shows that osteoporosis was somewhat less frequent and milder in degree at follow up than before operation but the difference is statistically insignificant. The fact that the change was so slight is obviously due both to the shortness of the follow up period and the severity of the disease.

Statistical analysis was performed as follows

The t test of dependent groups

$M_e = 15$ $t = 1.10$ $P > 0$[illegible] insignificant

The conclusion may be drawn that the great loss of calcium had not yet been compensated for at the time of the follow up examination although the patients had been using the feet operated upon

Table 33 *Osteoporosis in the subtalar joints in groups Op I and Op II*

Group	No. of feet	Talocalcaneal Stages 0–1	Talocalcaneal Stages 2–4	Calcaneocuboid Stages 0–1	Calcaneocuboid Stages [illegible]–4	Talonavicular Stages 0–1	Talonavicular Stages [illegible]–4
Op I	[illegible]84	[illegible]5	[illegible]09	27	25[illegible]	6[illegible]	1[illegible]
		26.4	73.6	9.5	90.5 %	[illegible]4	75.8 %
Op II	[illegible]48	[illegible]1	11[illegible]	56	19[illegible]	81	16[illegible]
		[illegible]8.6	71.4 %	[illegible]2.6	[illegible]7.4	3[illegible].7	67.3 %

Table 34 *The periosteal reaction in the subtalar joints in groups Op I and Op II*

Group	No. of feet	Talocalcaneal Stages 0–1	Talocalcaneal Stages [illegible]–4	Calcaneocuboid Stages 0–1	Calcaneocuboid Stages [illegible]–4	Talonavicular Stages 0–1	Talonavicular Stages [illegible]–4
Op I	[illegible]84	169	11[illegible]	233	[illegible]0	[illegible]	209
		[illegible]	40	82.1	17.6	[illegible]	73.6
Op II	[illegible]48	1[illegible]0	98	19[illegible]	[illegible]3	4[illegible]	19[illegible]
		60	39	78.7	21.3	19.8	80.[illegible] %

The periosteal reaction

The possible occurrence of periosteal growth in the subtalar joints after triple arthrodesis was studied. The observations made pre- and postoperatively were compared.

Table 34 clearly shows that no significant periosteal growth occurred after the operation. In the region of the CC and TN joints a slight reaction was observed, but when the changes in the two observation groups were statistically tested no significant differences emerged. No growth had occurred, while a significant difference in periosteal growth was observed between the different duration groups of the preoperative material (group Op I). In the talocalcaneal joint the periosteal reaction seemed rather to have decreased after operation, and the difference proved to be statistically significant ($P < 0.05$).

Statistical analysis

The periosteal reaction. Comparison of groups Op I and Op II by the t test of dependent groups.

Talocalcaneal joint $M_c = .09$ $t = 2.19$ $P < .05$ significant

Calcaneocuboid joint $M_c = .06$ $t = 1.36$ insignificant

Talonavicular joint $M_c = .08$ $t = 1.41$ insignificant

The arithmetic mean values of the tc changes in groups Op I and Op II were 1.31 and 1.24. The difference is only 0.07, but it shows that a slight improvement had occurred. This is to some extent in contrast to the periosteal reaction in the TN and CC joints. It is very difficult to evaluate the periosteal change in the talocalcaneal joint after arthrodesis. The dorsal *margin of the TN joint and the plantar margin of the CC joint are much* more readily distinguished on X ray films. It appears that the decrease that seemed to occur postoperatively in the periosteal reaction in the tc joint may be accounted for by the difficulty in evaluating the situation properly. As a result of fusion the osteophytes unite with the normal bone tissue, the posterior talar process is pressed tightly against the calcaneus and its length *can no longer be precisely measured.*

To summarize, no obvious periosteal changes, in any event no periosteal growth, occurred postoperatively in the tc, TN and CC joints.

Fusion after triple arthrodesis

Complete X ray studies were performed on 218 feet. In 117 cases these studies were carried out two to three years after operation. In 56 cases the interval was over seven years (Table 35). The best results were observed in

the talocalcaneal joint not a single case of non union being found In 58 cases (23 4 per cent) partial union had occurred In these cases part of the posterior joint surface was visible while the anterior portion was firmly ossified but in practice this is of no significance The calcaneocuboid joint showed non union in 16 cases (6 5 per cent) and partial union in 66 cases (26 6 per cent) Complete union of the CC joint was observed in 166 cases (66 9 per cent) The talonavicular joint exhibited non union in 23 cases (9 3 per cent) *partial union in 68 cases (27 4 per cent) and complete union in* 157 cases (63 3 per cent) In the cases showing partial union the lower portion of the CC joint had remained open while the area of the staple and the upper portion had fused On the other hand the upper margin of the TN joint had in some cases remained open These findings are obviously accounted for by incomplete contact of the points in question since at operation a *definite fissure sometimes perhaps al o cartilage had been left in these* sites The TN joint seems to cause most complications but no case of pseudarthrosis proper with mobility of the Chopart joint occurred Nine feet showed non union of both the TN and CC joints In two of these there was an obvious varus deformity causing discomfort One case exhibited rather marked varus of the forefoot *In one case non union was due to infection* and five years after the first operation sequestrectomy was performed on the Chopart joint which showed non union The infection healed but at follow up examination two years later union had not yet occurred Fibrous

TABLE 35 *Fusion after triple arthrodesis as observed at the follow up examination in the different duration groups*

Duration groups (years)	No of feet	Talocalcaneal TF	Talocalcaneal PF	Talocalcaneal NU	Calcaneocuboid TF	Calcaneocuboid PF	Calcaneocuboid NU	Talonavicular TF	Talonavicular PF	Talonavicular NU
<1	32	13	19	0	6	24	[illegible]	10	19	3
2–3	117	96	21	0	82	28	7	78	27	1[illegible]
4–6	43	40	3	0	36	5	2	29	12	[illegible]
>7	56	41	15	0	4	9	5	40	10	6
Total	248	190	58	0	166	66	16	157	68	23
		76 6	23 4	—	66 9	26 6	6 5	63 3	27 4	9.3

TF = totally fused
PF = partly fused
NU = non union

the wound area about five months after operation. After trepanation complete healing occurred within three months. In the third case a sequester and fistula developed five months after operation. Trepanation was performed and the ankle healed completely within eight months of the first operation.

The talocrural joint

The X-ray changes in the TC joint were studied both in the operatively and the non-operatively treated ankles. The follow-up results were compared with the pre-operative finding and the findings made at a corresponding point of time in the conservatively treated feet. In other words groups Op I and II, and Non-op I and II, were compared.

On comparison of groups Op II and Non-op II (Table 36) it appeared that stages 2—4 were throughout more frequent in the former. There was a corresponding difference at the first stage of this investigation between the feet assigned for operative treatment and those assigned for conservative treatment (Table 20). On comparison of groups Op I and Op II and Non

TABLE 36. *X-ray changes in the talocrural joint in groups Op II and Non-op II*

Group	No. of ankles	Osteoporosis Stages 0—1	Osteoporosis Stages 2—4	Narrowing of the joint space Stages 0—1	Narrowing of the joint space Stages 2—4	Osteoarthrosis Stages 0—1	Osteoarthrosis Stages 2—4
Op II	248	82	166	174	74	178	70
		33.1	66.9	70.2	29.8	71.8 *	28.[illegible] *
Non-op II	170	84	86	138	3[illegible]	134	36
		49.4	50.6 *	81.2	18.8	78.8	1[illegible]

TABLE 37

Group	No. of ankles	Surface erosion Stages 0—1	Surface erosion Stages 2—4	Marginal erosion, Medial part of mortise Stages 0—1	Marginal erosion, Medial part of mortise Stages 2—4	Marginal erosion, Lateral part of mortise Stages 0—1	Marginal erosion, Lateral part of mortise Stages 2—4
Op II	248	158	90	68	180	83	165
		63.7	36.3	27.4	72.6	33.5	66.5
Non-op II	170	129	41	89	81	97	73
		75.9	24.1 *	52.3	47.7	57.0	43.0

Table 38 X ray changes in the talocrural joint in groups Non-op I Op I Non-op II and Op II (stages [illegible])

Group	No of ankles	Osteoporosis	Narrowing of the joint space	Erosive changes: Surface	Erosive changes: Marginal, medial part of mortise	Erosive changes: Marginal, lateral part of mortise	Osteo arthrosis
Non-op I	[illegible]04	69	[illegible]0	3[illegible]	50	50	[illegible]1
		33 8	9 8 *	1[illegible] *	[illegible]4 [illegible]	24 [illegible]	10 3
Op I	[illegible]84	1[illegible]6	40	[illegible]9	96	[illegible]0	36
		44 4	14 1	[illegible]0 8	33 8	31 [illegible]	1[illegible]
Non op II	1[illegible]0	8[illegible]	3[illegible]	41	81	73	36
		[illegible]0 6 *	18 8 *	[illegible]4 1 *	4[illegible] 6	4[illegible] 9	[illegible]
Op II	24[illegible]	166	[illegible]4	[illegible]0	180	16[illegible]	[illegible]0
		66 9	[illegible]9 8	36 3	[illegible] 6	66 [illegible]	[illegible]

op I and Non-op II (Tables 20—21 and 36—37), it emerged that in the two series of feet the operatively treated and the non operatively treated the differences between the observations made at the two different stages were of about the same magnitude In both the disease had progressed In the operatively treated series surface erosion of the TC joint had increased from 20 8 per cent to 36.3 per cent The frequency of erosions of the malleolar mortise had increased in the operatively treated series by more than two fold and in the conservatively treated series by about twofold The percentage figure expressing the frequency of joint space narrowing was doubled in both series The increase in osteoporosis was somewhat slighter in the operatively treated series in the non operatively treated series it was about twofold When the erosive changes of the medial and lateral surfaces were compared (Table 38) medial changes were found to be somewhat more frequent postoperatively than before triple arthrodesis The same phenomenon was observed in the conservatively treated series although not so clearly In other words erosion of the cartilage and bone seem to be more pronounced in the surface of the medial malleolus and the opposite surface of the talus than in the corresponding lateral aspects It is possible that valgus of the foot plays a part in this respect the stress on the ligaments of the medial portion being perhaps heavier so that the »normal» progress of erosion is obscured

On analysing the distribution of the changes in the TC joint in the different duration groups (Tables 39 and 40) it was found that all symptoms

TABLE 39 Postoperative X ray findings in the talocrural joint in different duration groups as counted from the operation to the follow-up

Duration groups (years)	No of ankles	Osteoporosis Stages 0	1	2	3	4	Narrowing of the joint space Stages 0	1	2	3	4	Osteoarthrosis Stages 0	1	2	3	4
<1	33	1	[illegible]	13	8	0	[illegible]	3	[illegible]	[illegible]	1	[illegible]	1	1	1	[illegible]
		3 0	15 3	57 5	4	—	66 6	11	6 1	6 1	1 1	7 8	7 0	7 0	1 1	6 1
2–3	117	2	1	57	[illegible]	0	68	15	13	17	4	73	1	17	10	[illegible]
		1 7	21 8	18 7	18 8	—	58	12 8	11 1	11	3 4	6 4	1 8	11	8 6	1
4–6	45	10	6	24	5	0	31	4	6	[illegible]	[illegible]	3	4	1	[illegible]	1
		[illegible]	13 3	53 4	11 1	—	69 0	8 9	13 3	4 4	4 4	61	8	0 0	4 4	[illegible]
>7	53	8	14	16	12	3	8	3	5	4	13	[illegible]	6	[illegible]	10	3
		15 1	26 4	30 2	22 6	5 7	[illegible] 8	5 7	9 4	7 5	[illegible]	47	11 4	16 8	18	5 7
Total	18[illegible]	8	51	116	47	3	149	[illegible]	6	[illegible]	3	152	6	36	6	8
		11 3	21 8	46 8	18	1	60 1	10 1	10	10 1	[illegible]	61 3	10 5	11	10	3

TABLE 10 Postoperative X ray findings in the talocrural joint in different duration groups as counted from the operation to the follow up

Duration groups (years)	No of ankles	Surface erosion					Marginal erosion									
							Medial part of mortise					Lateral part of mortise				
		Stages					Stages					Stages				
		0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
<1	33	10	11	7	3	2	3	6	16	8	0	1	8	16	5	0
		30	33 4	21 2	11	6 1	11	18 3	48 4	24 2	—	3 1	24	48 4	15 3	—
–3	117	38	33	3	13	1	1	0	51	30	1	16	2	61	17	1
		3 5	28	27 2	11 1	0 9	10 3	17 1	43 4	25 6	0 9	13 7	18 8	52 1	11 5	0 9
4–6	45	1	13	6	3	[illegible]	5	12	18	10	0	6	13	19	7	0
		16 7	8 9	13 3	6 7	4 4	11 1	6 7	40 0	2 2		13 3	8 9	4 2	15 6	—
>7	53	18	11	4	1	2	1	6	4	19	0	4	10	9	11	0
		34 1	26 4	7 5	[illegible]	3 1	7 5	11 3	15 9	36 0	—	7 5	18 1	17 3	20 4	—
Total	48	87	71	19	31	10	1	11	11	67	1	10	3	11	13	1
		35 1	28 6	19 8	1 5	4 0	17	17 7	1 5	7 0	0 4	1 1	1 4	18 8	17 3	0 4

showed a slow and rather steady progression The differences between the first and the last duration groups were particularly marked Osteoporosis however, showed a steady improvement, from 81 7 per cent in the first group to only 58 5 per cent in the last The latter value is clearly higher however, than the value obtained before operation (11 1 per cent) but slightly lower than the value for the over 10 years duration group (59 7 per cent) The strikingly high frequency of osteoporosis postoperatively is probably due to the inactivity of the ankle In respect to osteoporosis a change for the better gradually occurs, but at the same time the disease progresses and influences the situation in the opposite direction Joint space narrowing and osteoarthrosis showed a definite aggravation As regards erosion, progression was relatively slow, and the greatest difference was noted between the first and the last duration groups It is striking that a definite although slight, tendency towards improvement was observed in the duration group 1—6 years in which the percentages of changes of stages 2—4 were lower than in any other duration group

As may be seen in Table 41 both in the conservatively and the operatively treated series erosions were by far most frequent in the toes (the mtp joints) and rarest on the surface of the TC joint In the former series these changes were fairly evenly distributed over the tarsal joints The frequency was clearly lowest in the cuneonavicular joint In both series the medial aspect of the TC joint seemed to show somewhat more marginal erosions than the lateral aspect In the Non-op II group the amount of erosions seemed to be about the same in the subtalar joints as in the marginal part of the TC joint In the Op I group (Table 42) this phenomenon is not obvious The tendency in question is not obvious either in the Non op I group, but it is very obvious in the Non-op II group (Table 42) This is probably due to the difference in material the operatively treated series comprising the most severely inflamed subtalar joints Initially the erosive changes in the subtalar joints were much more marked than the malleolar erosive changes *The increase in malleolar changes seems to reflect the progression of the disease*

As may be seen in Table 42 in the Non op I group the subtalar joints showed severer erosive changes than the TC joint even when the malleolar changes in the latter were taken into account The same observation was made in the Op I group, although the changes in this were throughout severer At follow up (Non op II) the differences had diminished except in respect to TC surface erosion (Table 42) This shows that the weight bearing surface of the TC joint is very resistant to the development of erosions An

Table 41 *The frequency of erosions in the different joints of the foot in groups Op II and Non op II*

Joint	Op II Stages 2–4	Non op II Stages 2–4
Metatarsophalangeal	2[illegible]9	1[illegible]
(1–5)	9[illegible] 3	93 [illegible]
Cuneonavicular	144	62
	[illegible]8 1	36 5
Talonavicular	—	73
	—	43 0
Calcaneocuboid	—	72
	—	4[illegible] 3
Talocalcaneal	—	67
	—	39 [illegible]
Surface of the TC	90	41
	3[illegible] 3	[illegible]4 1
Marginal medial	180	81
	[illegible]	47 6
Marginal lateral	16[illegible]	73
	66 [illegible]	4[illegible] 9

Table 42 *The frequency of erosions in the talocrural and subtalar joints in groups Op I, Non-op I and Non-op II*

Joint	Op I Stages 2–4	Non op I Stages 2–4	Non op II Stages 2–4
Surface of the TC	[illegible]9	3	41
	[illegible]0 8	1[illegible]	[illegible]4 1
Marginal medial	[illegible]	50	81
	33 8	21 5	47 [illegible]
Marginal lateral	[illegible]0	[illegible]0	73
	31 7	[illegible]	4[illegible] 9
Talocalcaneal	1[illegible]	[illegible]0	[illegible]7
	44 4	29	3[illegible] 5
Calcaneocuboid	140	[illegible]8	72
	4[illegible] 3	33 3	42 [illegible]
Talonavicular	174	[illegible]2	73
	[illegible]1 3	[illegible]4	43 0

increase in erosions is an obvious accompaniment of the progression of the disease except in the medial mortise of the TC joint in which erosive changes develop relatively quickly, i e during the first three years obviously owing to the presence of valgus deformity Operation does not seem to influence the formation of erosions of the malleolar mortise of the TC joint since the differences between the changes in the Op I and Op II groups and the Non-op I and Non-op II groups respectively were of the same magnitude (Table 38)

Statistical analysis

Comparison of the groups Op I and Non-op I (the U test page 66)
Comparison of the groups Op II and Non-op II (by the U test)
Surface erosion $z = 2.75$ $P < 0.01$ most significant
Marginal erosion medial part of the mortise $z = 5.15$ $P < 0.001$ highly significant
Marginal erosion lateral part of the mortise $z = 4.76$ $P < 0.001$ highly significant
Comparison of the groups Op I and Op II (the t test)
Surface erosion $M_c = -0.50$ $t = 9.28$ $P < 0.001$ highly significant
Marginal erosion medial part of the mortise $M_c = -0.99$ $t = 16.10$ $P < 0.001$ highly significant
Marginal erosion lateral part of the mortise $M_c = -0.85$ $t = 11.25$ $P < 0.001$ highly significant
Comparison of the observation groups Non-op I and Non-op II (the t test)
Surface erosion $M_c = -0.33$ $t = 6.98$ $P < 0.001$ highly significant
Marginal erosion medial part of the mortise $M_c = -0.77$ $t = 11.08$ $P < 0.001$ highly significant
Marginal erosion lateral part of the mortise $M_c = -0.67$ $t = 10.55$ $P < 0.001$ highly significant

Summary

The radiological changes in the TC joint were studied in the operatively treated feet before operation and at follow up and in the non operatively treated feet at corresponding points of time On the basis of the results it may be stated that the progression of the disease is accompanied by a steady progression of all radiological changes The progression of surface erosion was statistically highly significant while the progression of erosion on the lateral aspect was most significant On the medial aspect the progression was not statistically significant

Both in the operatively and the non operatively treated series very obvious differences emerged between the radiological findings made before operation in the former and at a corresponding point of time in the latter and at follow up. In the operatively treated series the changes were severer at both examinations than in the non operatively treated series. In both the radiological changes seemed to show the same rate of progression.

Statistically only the erosive changes in four groups were compared: Op I and Op II, Non-op I and Non-op II, Op I and Non-op I, and Op II and Non-op II. All differences proved to be highly significant. From this the conclusion may be drawn that the differences between the Op I and Op II groups on the one hand and the Non-op I and Non-op II groups on the other were of the same magnitude. In other words *operation does not seem appreciably to influence the development of radiological changes in the TC joint. The changes are obviously caused by rheumatoid arthritis.*

Instability of the ankle joint after triple arthrodesis

Previous investigations on the tilting of the talus in normal and injured ankle joints

BERRIDGE and BONNIN (1944 and BONNIN 1950) have shown that [illegible] per cent of normal subjects show tilting of the talus secondary to relaxation of the fibular collateral ligaments. This they called hypermobile ankle. Trochlear tilting laterally forming an angle of 5—[illegible] degrees with the tibial articular facet was observed in some cases and caused no discomfort. No instance of similar flaccidity of the deltoid ligament was noticed.

LEONARD (1949) found that after rupture of the anterior talofibular ligament the ankle was relatively stable at 90 degrees while the foot showed instability of the long axis as well as of the vertical axis of the talus when held in equinus position.

According to ANDERSSON et al. [illegible] *and* [illegible] *the calcaneofibular ligament* is also very important although the greatest instability is caused by combined rupture of this and the anterior talofibular ligament. Talar tilting was estimated by ANDERSSON et al. in degrees. Rupture of the calcaneofibular ligament caused tilting of [illegible] degrees and if the talofibular ligament too was ruptured the resulting lateral tilting of the talus was as much as 30 degrees. Furthermore anterior subluxation of the talus was observed in radiological stress investigations when the anterior talofibular ligament was ruptured. When the ankle was kept in 90 degrees angulation the talus was dislocated by 2 [illegible] mm; when the ankle was kept in equinus the dislocation was greater.

RUBIN and WITTEN (1960 and 1962) examined the talar tilt with the ankle [illegible] using great stress with a device of their own. They concluded that there is a wide variation in the normal talar tilt angle which makes it very difficult to extract reliable information regarding rupture of the fibular collateral ligaments of the ankle.

NEVIN and PO[illegible] (196[illegible]) studied 20 ankles in limbs to be amputated. The ligaments of the ankle were cut under anaesthesia. The investigators found that talar tilt of [illegible]

the cases in association with trauma It seems possible that the stretching, wearing or destruction of the ligaments or capsules due to RA affect the stability of the ankle RA also has a contrary effect, however in that it leads to anchylosis of the joints Narrowing of the talocrural joint space and anchylosis prevent the development of instability of the ankle

In the present study the lateral ligaments were surgically explored in a total of 13 cases (in 3? by the author) in which a radiological stress examination had been performed The exploration of the ligaments was made in connection with triple arthrodesis The anterior talofibular and calcaneofibular ligaments were mostly measured to the nearest millimetre In five cases the deltoid ligament was also examined Biopsy specimens for histological study were almost invariably taken from the lateral margin of the ligaments and the surrounding tissue The talocrural joint was simultaneously inspected and if proliferation of the synovial membrane was observed synovectomy and biopsy were carried out

In studying instability of the ankle a mechanical device, constructed in the Hospital of the Rheuma Foundation was used in order to avoid the risks of irradiation (Plate 1 p 19)

At follow up examination talar tilting was measured in 255 ankles on which triple arthrodesis had been performed In addition, 200 non operated ankles were studied The control material consisted of 60 ankles showing

TABLE 43 *Tilting of the talus in the Op II Non-op II and control groups*

Group	*Tilting* Lat/Med	No of feet	0	1–5	6–10	11–15	>15
Op II	Lateral	255	111	86	48	7	3
		%	43.5	33.8	18.8	2.7	1.2
	Medial	255	140	96	11	2	0
			57.3	37.6	4.3	0.8	–
Non op II	*Lateral*	200	105	59	35	1	0
			52.5	29.5	17.5	0.5	–
	Medial	200	129	67	4	0	0
			64.5	33.5	2.0	–	–
Controls	*Lateral*	*60*	22	31	7	0	0
			36.6	51.7	11.7	–	–
	Medial	60	30	30	0	0	0
			50.0	50.0	–	–	–

TABLE 44 *Tilting of the talus after triple arthrodesis as measured at follow-up examination in different duration groups*

Duration groups (years)	No of ankles	Degrees of lateral talar tilt 0	1–5	6–10	11–15	>15	Degrees of medial talar tilt 0	1–5	6–10	11–15	>15
<3	20	8	6	4	2	0	12	8	0	0	0
		40.0	30.0	20.0	10.0	—	60.0	40.0	—	—	—
4–6	51	21	12	14	3	1	30	19	1	1	0
		41.2	23.5	2[illegible].5	5.8	1.9	58.9	37.3	1.9	1.9	—
7–10	60	3	18	10	0	0	33	3	4	0	0
		53.3	30.0	16.7	—	—	55.0	38.3	6.7	—	—
>10	124	50	0	20	2	2	71	46	6	1	0
		40.3	40.3	16.2	1.6	1.6	57.3	37.1	4.8	0.8	—
Total	255	111	86	48	7	3	146	96	11	2	0
		43.5	33.8	18.8	2.7	1.2	57.3	37.6	4.3	0.8	—

TABLE 45 *Tilting of the talus in the conservatively treated feet in different duration groups*

Duration groups (years)	No of ankles	Degrees of lateral talar tilt 0	1–5	6–10	11–15	>15	Degrees of medial talar tilt 0	1–5	6–10	11–15	>15
<3	39	23	7	8	1	0	22	16	1	0	0
		58.9	17.9	20.5	2.7	—	56.3	41.0	2.7	—	—
4–6	30	15	9	6	0	0	21	9	0	0	0
		50.0	30.0	20.0		—	70.0	30.0	—		—
7–10	43	25	12	6	0	0	28	14	1	0	0
		58.2	27.9	13.9	—	—	65.1	32.6	2.3	—	-
>10	89	42	31	15	0	0	58	28	2	0	0
		47.7	35.[illegible]	17.1	—	—	66.0	31.8	2.2	—	—
Total	200	105	59	35	1	0	129	67	4	0	0
		52.5	29.5	17.5	0.5	—	64.5	33.5	2.0	—	—

neither trauma nor disease The results are shown in Tables 43, 44 and 45 Lateral tilting of over 5 degrees occurred in 22 7 per cent in the Op II group, in 18 0 per cent in the Non op II group, and in 11 7 per cent in the control group Medial talar tilting of over 5 degrees was observed in only 5 1 per cent in the Op II group in 2 0 per cent in the Non-op II group and in 0 per cent



Plate 4 Stress investigation of the ankle in which the device shown in plate 1 was used In this case there is marked lateral tilting (of 17 degrees) The ankle is in mid position (90—100 degrees)

in the controls In 13.5 per cent in the Op II group and in 32 5 per cent in the Non-op II group no lateral tilting angle was pre ent In other words, the latter group showed less tilting It is al o strikin, that large tilting an gles i e over 10 degrees were rare in all groups

Table 16 hows the re ults of anteropo terior stress inve tigation In thi the calcaneus wa forcibly pre ed backwards and an attempt was made to subluxate the talus forward The material compri ed 53 ankles that had been operated upon and 68 con ervatively treated ankle which were compared Obvious subluxation was observed in 14 feet (26 4 per cent) in the former group and in 13 feet (19 1 per cent) in the latter Only cases in which the joint surfaces of the tibia and talus were clearly eccentric were regarded a positive

During the stress examination the majority of the ankle were at an angle of 90—100 degrees, or the po ition that the TC joint could be placed in without heavy stre s (plate 4) However, for the sake of compari on 64 ankles were studied in maximal pl antar flexion (stre was carried out by examinator s hands) in which the anterior talofibular ligament i expo ed to the greatest stre s on inversion (plate 5) The e 64 ca es were chosen at random from the follow up material consi ting of both operatively and



Plate 5 Stress inve tigation was performed with the ankle in maximal plantar flexion Marked osteoporo is is present No definite erosions r se n Unevennesses are observ able in the apices of the malleoli Marked lateral talar tilt of 1° degrees)

conservatively treated feet On comparison of the results of these examinations with those of the above-mentioned tests, it was found that talar tilting occurred under both types of experimental conditions, but it occurred somewhat more frequently and was somewhat more pronounced in plantar flexion Of the 64 feet thus examined, 20 (31.3 per cent) showed lateral tilting of over 5 degrees

The ankle thus showed maximal stability in midposition On inversion of the foot in this position the calcaneofibular ligament is first strained but of course twisting of the ankle is also prevented by the other ligaments and the capsule Table 47 shows the results obtained with the TC joint in maximal plantar flexion

In Table 11 the distribution of the talar tilt in four duration groups of the operatively treated series is shown For the sake of comparison the corresponding results in the conservatively treated series are presented in Table 1[illegible] In this table the duration is counted from the onset of RA in the foot until follow up examination Tilting seems to decrease with prolonga-

TABLE 46 *Inferior subluxation of the talus*

Group	No of feet	Subluxation	Uncertain subluxation	No subluxation
Op II	53	11 (6.4 %)	3 ([illegible]7 %)	3[illegible] (67.9 %)
Non op II	68	13 (19.1 %)	5 ([illegible])	50 (73.5 %)
Total	121	[illegible] ([illegible]3 %)	8 (6.6 %)	86 (71.1 %)

TABLE 47 *Lateral tilting of the talus (TC joint in maximal plantar flexion)*

No of feet	0	1–5	6–10	11–15	>15
64	13	31	19	1	0
	20.3	48.4	29.7	1.6	–

tion of the disease This development is influenced by narrowing of the TC joint space (which implies a tendency towards ankylosis) a feature which is not invariably present however *If narrowing does not occur tilting remains unaltered or increases*

TABLE 48 Tilting of the talus and narrowing of the talocrural joint in groups Op II and Non op II

Stage of narrowing of TC joint	Op II Non op II	No of ankles	Degrees of lateral talar tilt 0	1–5	6–10	11–15	>15	Degrees of medial talar tilt 0	1–5	6–10	11–15	>15
0	Op II	156	7	60	33	4	2	80	71	4	1	0
			36	38 0	1	[illegible]	1 2	51 4	45 5	[illegible]	0 6	—
	Non op II	138	73	40	24	1	0	91	47	0	0	0
		%	53 0	29 0	17 4	0 7	—	66 0	34 0	—	—	—
1	Op II	25	6	10	8	1	0	9	11	4	1	0
			24 0	40 0	32 0	4 0	—	36 0	44 0	16 0	4 0	—
	Non op II	[illegible]	11	9	6	0	0	5	11	7	0	0
			4 4	31 6	3 0	—	—	31 6	51 0	11 4	—	—
	Op II	6	10	[illegible]	[illegible]	1	1	15	[illegible]	[illegible]	0	0
			38 5	31 5	[illegible]	3 9	[illegible]	57 6	31 5	7 8	—	—
	Non op II	15	1	[illegible]	1	0	0	[illegible]	[illegible]	1	0	0
			6 7	16 6	6 7	—	—	60 0	33 4	6 6	—	—
3	Op II	[illegible]	17		2	1	0	1	3	1	0	0
			68 0	0 0	8 0	4 0	—	84 0	12 0	4 0	—	—
	Non op II	10	8		0	0	0	9	1	0	0	0
			80 0	0 0	—			90 0	10 0	—		—
4	Op II	3	1		0	0	0	21		0	0	0
			91 4	8 6	—		—	91 4	8 6			
	Non op II	11	3	1	1	0	0	11	0	0	0	0
			8 0	10	10			100 0	—	—		—

Total Op II 5[illegible] feet Non op II 00[illegible] feet



Plate 6. Lateral ligaments of the ankle photographed in connection with triple arthrodesis. The foot is in plantar flexion. The instrument is placed under the anterior talofibular ligament and the partly frayed joint capsule. Above the ligament may be seen the thin cartilaginous surface of the lateral corner of the talus (TC joint) and the lower point of the instrument rests on the calcaneofibular ligament, which is seen as a narrow cord when the peroneal tendons are drawn downward. Round the ligaments there is an abundance of inflamed tissue, particularly in the area of the tarsal sinus and round the lateral malleolus.

Table 48 shows the distribution of the tilting values according to narrowing of the TC joint space. It is clearly seen that talar tilt decreases with a gradual narrowing of the joint space. The most obvious decrease in talar tilt is found to occur in both the operatively and the non-operatively treated feet when narrowing of the TC joint space exceeds stage 2.

Statistical analysis

The comparisons are made by means of the U test. 1) Comparison of the control group (normal ankles) and the rheumatoid material (operatively and conservatively treated feet followed up).

Lateral and medial talar tilt was separately compared.

Lateral tilt in control group ←→ Op II + Non-op II group

$z = 0.19$ insignificant

Medial tilt in control group ←→ Op II + Non-op II group

$z = 1.2$[illegible] insignificant

2) Comparison of the operatively treated and the non-operatively treated rheumatoid material

Lateral tilt in group Op II ←→ group Non op II

z = 2 02 P< 05 significant

Medial tilt in group Op II ←→ group Non op II

z = 1 76 P< 05 significant

3) Comparison of the material (Op II and Non op II) examined in maximal plantar flexion and the material (Op II and Non op II) examined in mid position (90—100 degrees)

Only the change in lateral talar tilt was analysed

z = 3 71 P< 001 highly significant



Plate 7 Photograph of the partly destroyed anterior talofibular ligament The latter is thinner and narrower than normal

1) Subluxation of the talus. Comparison of the operatively treated and the conservatively treated material

Group Op II ⟷ Group Non-op II

$z = 0.77$ insignificant

Operative findings in the lateral ligaments of the ankle

The anterior talofibular ligament was completely denuded and measured to the nearest millimetre in 28 cases. In a further four cases the ligament was destroyed to such a degree that measurement was impossible, and in 11 cases the size of the ligament was estimated.

As a rule the *anterior talofibular ligament* had retained its length, since the degenerative changes made it thinner or narrower mainly in the area of the insertions. In these sites holes were sometimes seen and they looked frayed and torn (Plates 6 and 7). The ligament could also be swollen and covered by inflamed synovial membrane. The breadth was measured at the middle of the ligament and the length in the mid longitudinal axis from one insertion to the other. The mean breadth in 32 cases was 11.4 mm. In four of these cases the ligament was so torn and destroyed that it was regarded as lacking, and in 11 cases the ligament was oedematous and appeared to be stretched but at the same time it was clearly thinner and narrower than normal.

The mean length of the anterior talofibular ligament (28 cases) was 19.4 mm. When the four destroyed ligaments were included a mean length of 17.0 mm was obtained (32 cases). The former figure however seems to express the mean length of this ligament more adequately, since the ligament loses its true length immediately when it is broken or detached from the malleolus or talus.

The *calcaneofibular ligament*, too, was inspected in all 13 cases, but its breadth was only measured in four cases, in which the mean breadth was 5.5 mm. In three cases the ligament was so completely destroyed that neither its thickness nor breadth could be measured, and in 35 cases it was oedematous, softened or frayed, although the ligament as such was strong.

The calcaneofibular ligament was much thicker and longer than the anterior talofibular ligament, but it was clearly narrower than the latter. In five cases there seemed to be no signs of inflammation or degeneration.

The *deltoid ligament* was found to be intact in the feet examined, although it was sometimes oedematous.

In these cases totalling 7 in which the ligaments (anterior talofibular or calcaneofibular) were entirely frayed the duration of the disease was nearly 30 years in three cases 5 years in one case and 3 years in three cases It appears that in cases of long standing degeneration and persistent stress destroy what remains of the ligaments The ankle was completely stable in six of these cases In all these cases TC joint changes of stages 3—4 were present In the seventh case the TC joint changes were of stage 1 and there was a lateral talar tilt of 6 degrees In this case the duration of the disease was 5 years The patient reported that the ankle sometimes gave way, but no major harm was caused

On histological examination it was almost invariably found that inflamed synovial tissue had invaded the tissues round the anterior talofibular ligament or the interfibrillar spaces In many cases the fibres of the ligaments seemed to be stretched and swollen They also showed degenerative changes and sometimes part of the fibres were so completely destroyed that the structure of the ligament was no longer clearly distinguishable

Summary

In rheumatoid feet tilting of the talus seems to decrease with prolongation of the disease Narrowing of the TC joint space is associated with decrease and finally total disappearance of talar tilt This development is very obvious when the joint space shows marked (stage 3) narrowing If narrowing does not occur tilting may increase On operative exploration of 43 cases only four were found in which the anterior talofibular ligament was entirely frayed, the calcaneofibular ligament was destroyed in three cases In these cases the duration of the disease ranged between 3 and 30 years Statistically no significant difference was observed between the normal control material and the rheumatoid material in respect to talar tilt

On the other hand a clear statistically verified difference in tilting was observed between the operatively and conservatively treated groups The difference was obvious both as regards medial and lateral tilting In other words *operation clearly caused an increase in tilting* In respect of the tendency towards anterior subluxation of the talus no significant difference emerged between the operatively and non-operatively treated ankles Hence it appears that the anterior talofibular ligament is not injured at operation Lateral tilting was significantly greater in maximal plantar flexion than it was in tests performed on the same ankles in midposition This clearly shows the important part played by position in studies on the stability of the ankle

Osteoarthrosis of the talocrural joint as a complication after triple arthrodesis

Previous investigations

Many authors have mentioned the development of osteoarthrosis in the TC joint as a possible complication

Arthrosis of the TC joint diminishing the movement of the joint was reported as a complication after subtalar arthrodesis by HART (1937) BENTZON et al (1949) and MACKENZIE (1959) The last mentioned investigator observed arthrosis only in patients followed up for over 11 years i e in 15 cases (in a series comprising 182 operations by LAMBRINUDI s method) In addition MACKENZIE observed 17 cases of flattening of the talus due obviously to avascular necrosis of the talus These findings were made after an observation period of at least six years LEIKKONEN (1950) and LINDHOLM (1960) also reported this complication after LAMBRINUDI s arthrodesis and WHITMAN s astragalectomy In these cases the operations had been performed on poliomyelitic or otherwise paralyzed feet showing a disturbed muscular balance The TC joint was often instable and the conditions for the development of arthrosis were thus favourable HOWLAND (1961) observed arthrosis of the TC joint at follow up in one ankle (out of 129 on which triple arthrodesis had been performed) RUETVEIT (1961) in a series of 37 extra articular arthrodeses, observed no complications in the form of arthrosis or instability of the TC joint WILSON et al (1965) did not mention this complication in a report on 301 triple arthrodeses The development of arthrosis after triple arthrodesis in an otherwise sound TC joint seems to be of rare occurrence and a very slow process

Present investigation

No follow up studies after triple arthrodesis on patients with [illegible] toid arthritis have been published and therefore no information [illegible] able concerning postoperative development of arthrosis of the [illegible] This might reasonably be thought to occur since the inflamm[illegible] involve this joint also However in the present series arth[illegible] joint was relatively rare In the group assigned for operation [illegible] operatively in 12 7 per cent and at follow up in 28 2 per [illegible] At corresponding points of time osteoarthrosis was [illegible] conservatively treated group in 10 3 per cent and 21 2 pe[illegible] In the former group osteoarthrosis thus increased some[illegible] the latter surface erosion increased from 20 8 per cent [illegible]

the operatively treated group and from 13 7 to 21 1 per cent in the conservatively treated group The osteoarthrosis seems to be a phenomenon secondary to inflammation The progression of osteoarthrosis was more obvious in the operatively treated material Instability of the TC joint was also a more common finding in the operatively treated series in which it attained statistical significance

Summary

The conclusion may be drawn that the development of osteoarthrosis in the feet operated upon was influenced by the triple arthrodesis and the instability of the TC joint due to the operation In these cases flattening of the talus was sometimes observed Osteoarthrosis was found to be relatively rare and caused no trouble The most serious problem is constituted by the steady progression of the rheumatoid changes in the ankle

Functional results

The evaluation of the functional results of 290 triple arthrodeses was based on 1) the subjective view of the patient (most important) 2) clinical examination and 3) radiological findings

Only 38 patients, i e 10 men and 28 women were not quite satisfied with the operative result In four of these cases triple arthrodesis had been performed bilaterally and both feet caused discomfort A total of 42 feet (14 5 per cent) were painful and the patients subjective estimations were based on the presence of this symptom Only in 17 cases (5 9 per cent) was the result so poor that in the patient s opinion no benefit had been derived from operation In 25 feet (8 6 per cent) the result was fair in the sense that the situation was better than before operation since the pain was alleviated (Table 49)

TABLE 49 *The functional results of the 290 triple arthrodeses*

Sex	L/R	No of feet	Final result		
			Good	Fair	Poor
Female	L	98	83	9	6
	R	112	96	11	5
Male	L	41	36	4	1
	R	39	33	1	5
Total (227 patients)		290	248 85 5 %	25 8 6 %	17 5 9 %

Fair and poor 42 feet 14 5 %

The main causes of failure in these subjectively unsuccessful cases appeared to be the following (Table 50)

1) planovalgus 17 feet (5.9 per cent)
2) pes varus or calcaneovarus 10 feet (3.4 per cent)
3) Varus of the forefoot 6 feet (2.1 per cent)
4) Functional impairment of the talocrural joint 4 feet (1.4 per cent)
5) Other causes 5 feet (1.7 per cent)

On anatomical examination planovalgus was found to be extreme in 13 cases while deformity of stage 3 was present in four cases The calcaneovarus deformity was of stage 4 in one case of stage 3 in four, and of stage 2 in the remaining five cases All six cases of varus of the forefoot were of stage 3 The group under discussion includes four cases in which the chief cause of discomfort was the TC joint, which showed marked swelling and erosions (stage 3) Since these four TC joints were painful and already showed obvious radiological changes at the time when triple arthrodesis was performed it would have been better to make a pantalar arthrodesis These cases are counted among the complications of triple arthrodesis because the operation did not benefit the patient

In no case in the group with complications was instability present to such a degree as to be subjectively regarded as important Lateral talar tilt of over 5 degrees was present in only 10 ankles

Other causes of failure consisted of pseudarthrosis of the Chopart joint (two feet) pseudarthrosis of the TN joint (one case), fistulating osteitis (in one case in which heterogenous bone had been applied) and severe rheumatoid inflammation of the cuneonavicular joint (one case) All the three feet with pseudarthrosis showed varus deformity and moderate varus of the forefoot was present in the patient with an affected cuneonavicular joint The chronic fistulating osteitis eventually healed after trepanation and sequestrectomy which were carried out after the follow up examination The pseudarthrosis of the TN joint was later corrected by arthrodesis and the foot showing pseudarthrosis of the TN and CC joints as well as varus was assigned for repeated arthrodesis In the two severest cases of varus of the forefoot a wedge resection was planned to be performed in the area of the os cuneiforme metatarsus I

Five patients were confined to wheel chairs owing to rheumatoid changes in the hips and knees and their ankles had therefore hardly been subjected to weight bearing Nonetheless they were satisfied with the operative results because of the relief from pain On 12 patients bilateral triple arthrodesis had been performed and in each of them one foot showed moderate

or severe deformity (only four of the patients showed deformity of both feet) In all bilateral arthrodeses had been carried out on 63 patient. The present results by no means indicate that bilateral triple arthrodesis would increase the rate of functional complications

In the cases with complications (12 feet) the mean duration of the disease was 7 6 years which largely corresponds to the mean duration in the whole material (7 2 years) This shows however that the disease was of very old standing in the e 12 feet before they were operated upon In only 10 feet was the duration less than three years

Summary

There is a considerable difference between the anatomical and functional results Not even moderate planovalgus seems to cause the rheumatoid patient much discomfort and the extreme deformities observed at follow-up examination were few This implies that the patients placed a very high value on the relief from pain Varus is an embarrassing deformity but in the present material it was relatively infrequent Marked varus of the forefoot also impedes walking Planovalgus is the most common deformity which in severe form causes daily discomfort as soon as the patient moves about Radiological changes of the TC joint were strikingly frequent in the present series (Table 38) but at follow-up examination only four patients complained spontaneously of marked pain All of these also showed erosions of stage 4 in the weight bearing surfaces of the joint Furthermore the cessation of the rheumatoid process in the cuneonavicular and metatarso-tarsal joints is noteworthy Only one patient had a very painful cuneonavicular joint on which it was planned to perform arthrodesis

TABLE 50 *The functional results of the 90 triple arthrodeses The main cause of failure*

Result	No of feet	Plano valgus	Calcaneo varus	Varus of the forefoot	TC inflammation	Other causes
Fair	25 8 6 %	11	6	3	3	2
Poor	17 5 9	6	4	3	1	3
Total	42 14 5 %	17 5 9	10 3 4	6 2 1	4 1 4 %	5 1 7 %

in the 2—3 years duration group in 82.6 per cent. After this no major changes occurred. Other deformities were relatively infrequent. The development of planovalgus is associated with an increase in the angle between the talus and the floor. In the author's opinion the development of planovalgus in the initial stage of the disease reflects the violence of the inflammation. The arch of the foot does not tolerate weight bearing when the soft tissues are inflamed. When the patient avoids weight bearing on the median ray and steps more on the lateral margin of the foot, the forefoot may twist into varus.

According to VAINIO (1956) planovalgus is by far the most common deformity of the foot in adult rheumatics. The present findings tally with his. VAINIO stated that planovalgus is an early sign. According to ISEMEIN and FOURNIER (1963) and LONGSTIER (1963), valgus deformity may develop in a very early stage and LONGSTIER suggested that it may be due to spasm of the peroneus muscle.

The functional anatomy of flat foot and the factors influencing the development of this deformity have been dealt with in numerous studies, e.g. those of v. LANZ and WACHSMUTH (1938), HOHMANN (1948), NIEDERECKER (1959), SCHOBERTH (1963). According to NIEDERECKER and SCHOBERTH, the navicular is elevated and laterally displaced and consequently the head of the talus »falls down» toward the medial side of the foot, in the plantar direction.

The head of the talus is in part supported by the surface of the sustentaculum tali of the calcaneus and in part it rests on the strong plantar calcaneonavicular ligament. The anatomy of the latter was studied by SOERGEL (1959) among others. According to him the longitudinal fibres of the ligament counteract longitudinal dislocation of the talus while the transverse fibres counteract the orthostatic pressure. Changes in the ligament immediately affect the maintenance of the position of the head of the talus.

According to the present observations rheumatoid arthritis causes violent inflammation of the talonavicular joint and the tarsal sinus, on the deep surface of which the strong plantar calcaneonavicular ligament rests. A diffuse inflammation influences the statics of the foot as a whole. In a normal foot weight bearing falls chiefly on the medial ray. It is therefore understandable that the rheumatoid patient, in order to avoid pain, tries to step on the outer margin of the foot. This causes elevation of the medial aspect, compensatory pronation of the calcaneus, and valgus. If the calcaneus is bent into varus in a normal foot, the interosseous talocalcaneal ligament becomes tense. If the ligament in question is weakened or destroyed,

it cannot prevent the calcaneus from slipping into varu which may sometimes happen as a result of very strong active inflammation and an erroneous distribution of weight bearing Obviously the anterior tibial muscle draws the forefoot into supination, just as the short peroneal muscle draws the hindfoot into pronation which may be due to pasm provoked by the inflammation

Conclusions

The following conclusions may be drawn from the foregoing When the sublalar joints become inflamed swelling pain at rest pain on weight bearing and the development of planoralgus are early signs The deformity develops as early as within three years from the occurrence of the first signs in the foot This observation is statistically significant Planovalgus is by far the most common deformity The clinical symptoms in the talocrural joint increase when the sublalar joints are inflamed but later they decrease and persistent violent inflammation of the T C joint is rare

Radiological findings

Osteoporosis

Osteoporosis occurred most frequently in the area of the calcaneocuboid joint (90 5 per cent) Hall (1960) established that in the neck of the cal caneus and cuboid the bony trabeculae exhibit changes in direction which decrease the radiographic density of the bone Even normally this area is therefore less dense than the region of the anterior margin of the posterior talocalcaneal joint This source of error was eliminated in the present study by comparing the changes present in the same area at different examina tions The reliability of the results is to some extent however jeopardized by technical sources of error Soila (1958) al o reported that the develop ment of osteoporosis in the area of the cuboid tuberosities was a significant and frequent sign In the present study statistical analysis revealed a sig nificant impairment of osteoporosis with prolongation of the disease in the area of the tc and TN joints while in the CC area the differences between the various duration groups were insignificant This seems to indicate that osteoporosis in the area of the CC joint is an early sign of RA This also appears from the diagram in Fig 5

In the area of the talocrural joint osteoporosis occurred in 44 4 per cent of cases which is clearly lower than the corresponding ratios for the triples

joint. A slight improvement was observed in the 1—6 years duration group, after which the condition steadily progressed (Table 22). This may in part be due to inactivity on account of inflammation of the subtalar joints, in part to the rheumatoid process in the TC joint.

Narrowing of the joint space

Severe narrowing of the joint space (stages 3—4) occurred by far most frequently in the talonavicular joint. Between narrowing of the CC and TC joint space and the duration of the disease a significant correlation was observed, while the corresponding relationship for the TN joint space did not attain statistical significance. This shows that narrowing of the TN joint space mainly occurs during the first three years and is thus an early sign of RA. Subsequently only slight changes occur. This observation is consistent with the finding that planovalgus develops during the initial stage of the disease.

The talocrural joint space showed narrowing in 10 cases (11.1 per cent) and this sign steadily progressed with prolongation of the disease (Table 2?). Narrowing of the TC joint space was relatively infrequent. In this respect there was an obvious difference between the talocrural joint and the subtalar joint.

Erosion

The frequency of erosions was highest in the talonavicular joint (see also Fig. 7), a finding which lacks a satisfactory explanation. Perhaps mechanical factors such as depression of the talus in association with the circulatory conditions play a part. BYWATERS (1963) and MARTEL (1963) suggested that usage of the joint and mechanical factors combine to produce erosive change. The present study showed, however, that erosion steadily progressed although the range of motion decreased and deformities became fixed. Consequently the development of erosions must be dependent on the progression of RA. Owing to its unfavourable position the TN joint is subjected to particularly great mechanical stress, as also appears from the fact that during a period of three years planovalgus developed and advanced to a degree resulting in subluxation. The progress of erosion in this joint was found to be significantly correlated with the duration of the disease. Probably mechanical factors do not offer a sufficient explanation of the fact that the erosive changes were severer in the TN joint than in the other joints examined. The joints of rheumatoid fingers and toes show marked erosion although the mechanical stress to which they

normally are subjected is slighter than that to which weight bearing joints are exposed The development of erosions may very well also be influenced by the vascular conditions and vascular necrosis

It was decided to assess the erosive changes in different areas of the TC joint separately because it was found during the course of the investigation that the initial rheumatoid signs in this joint apparently consist of small unevennesses in the lateral and medial surfaces of the mortise the surfaces of the malleoli or talus or the surface of the marginal parts of the joint at the border between the articular cartilage and the bone In this area erosive change occur as surface roughness as tiny cyst-like formations or as obvious erosion

In the surface of the talocrural joint (the main weight bearing surface) erosions were observed in only 59 feet (20 8 per cent) while erosions were noted in the medial aspect of the mortise in 96 feet (33 8 per cent) and in the lateral aspect in 90 feet (31 7 per cent) In the malleolar portion of the mortise erosions were thus clearly more frequent than in the surface of the joint The changes obviously progressed with prolongation of the disease at least in the joint surface and the lateral aspect This observation was statistically highly significant as regards the joint surface and significant as regards the lateral aspect Erosions of the medial aspect of the mortise often seem to be an early sign since the differences between the duration groups were insignificant This observation is consistent with the observation concerning the development of planovalgus deformity via the deltoid ligament the latter influences the medial malleolus and may cause erosive changes

Aggravation of the erosive changes of the TC joint was also very clearly observed in the conservatively treated feet (Tables 24 and 25)

Periosteal reaction

According to ANSELL (1963) true periostitis in which the periosteum is elevated from the bony surface seems frequently to occur in the more proximal parts above the malleoli as a rule at the margin of the medial aspect of the tibia In the distal parts of the malleoli true periostitis does not seem to occur and this phenomenon is therefore outside the scope of the present study

The severest changes were observed at the margins of the TN joint If slight forms (stage 1) are included the frequency was somewhat higher in the talocalcaneal joint The arithmetical mean of the stages of severity was

highest for the TN joint (Fig. 8). With prolongation of the disease a statistically significant increase in the frequency of changes was observed in all three joints. Periosteal changes occurred most frequently at the margins of the TN, tc and CC joints and they seemed to be caused by rheumatoid arthritis.

Osteoarthrosis

In the area of the CC and tc joints osteoarthrosis seemed to progress rather steadily, in the TN joint less steadily (Table 19). In the TN joint osteoarthrosis was observed in 30.7 per cent in the first duration group, and in 38 feet (61.3 per cent) in the second duration group (4—6 years). In this group the frequency was highest. It appears that the development of planovalgus in the first duration group leads to the development of secondary osteoarthrosis, which reaches its maximum in the next duration group. On statistical analysis the differences between the various duration groups were found to be significant also in regard to the TN joint, although the level of significance was lowest on this point. Obviously this is due to the changes caused by planovalgus during the initial stage of the disease. Otherwise the exacerbation of osteoarthrosis followed the progression of RA. In the talocrural joint, too, osteoarthrosis showed an obvious aggravation with prolongation of the disease (Table 22). A similar development was observed in the conservatively treated material (Table 21), although severe changes were less frequent. Arthrosis is known to develop as a secondary phenomenon in an inflamed joint. The differences observed between the various joints as regards the development of arthrosis are due not only to mechanical factors but also to the circulatory condition.

Conclusions

The TC joint is very resistant to inflammatory changes, but malleolar erosions clearly occur more often than surface erosions. Erosions of the medial malleolar mortise are early signs and obviously develop simultaneously with planovalgus. Narrowing of the talonavicular joint space is also an early sign, as was clearly revealed by its frequent occurrence in the under three years duration group. This change seems to be due to the development of planovalgus and depression of the talus. Osteoporosis of the calcaneocuboid area is an early sign. All other radiological changes — osteoporosis of the talocrural, TN and tc joints, narrowing of the talocrural, tc and CC joint spaces, erosions of the TN, CC and tc joints and of the surface and lateral aspects of the talocrural joint, periosteal changes at the margins of the »triple» joints and osteoarthro-

sis in all the pantalar joints — *show an obvious exacerbation with progression of rheumatoid arthritis*

The severest radiological changes are encountered in the TN joint osteoporosis excepted which is most severe in the area of the CC joint As regards severity, the changes in the talocalcaneal joint are between those of the TN and CC joints osteoporosis excepted The radiological changes in the talocrural joint are slighter than the corresponding changes in the subtalar joints

2 What are the practical consequences for the rheumatoid patient of arthrodesis of the subtalar and midtarsal joints?

Clinical findings

Swelling pain and range of motion

Swelling was observed postoperatively in 63 feet (21 7 per cent) while at a corresponding point of time swelling was noted in the conservatively treated material in 109 feet (56 2 per cent), or in other words clearly more frequently

At follow up examination moderate or marked pain at rest was present in only 10 operatively treated feet (3 4 per cent) In the operatively treated series pain on motion was preoperatively present in almost every case (98 6 per cent), and after operation in only 12 feet (4 1 per cent) In the conservatively treated series pain on motion was still present in 82 feet (42 2 per cent) at follow up examination In the operatively treated feet no motion was observed in the subtalar joints In the conservatively treated series motion was moderately or severely limited in 141 feet (72 6 per cent)

In the talocrural joint swelling obviously decreased after operation Moderate or marked pain persisted in only 18 TC joints (16 5 per cent), and slight tenderness on palpation in 162 ankles (55 9 per cent) Preoperatively dorsal flexion was under 10 degrees in 90 ankles (30 8 per cent), at follow up examination in 105 (36 2 per cent) Plantar flexion was under 20 degrees (stages 2—4) in 109 ankles (37 3 per cent) before operation, and in 137 ankles (47 2 per cent) at follow up The range of motion had thus decreased during the observation period

Deformities

The most noteworthy observation was the change in degree of severity that the planovalgus deformity underwent after operation Preoperatively moderate planovalgus was present in 127 feet (43 6 per cent) *and severe*

extreme planovalgus was present in 128 feet (43 8 per cent) At follow up when calcaneal valgus was measured in degrees, moderate valgus (11—15 degrees) was present in 193 feet (66 5 per cent), while severe or extreme valgus (more than 15 degrees) was present in 66 feet (22 8 per cent) The most obvious change was an improvement in the severest deformities *At operation an attempt was not always made to place the calcaneus into mid position but an attempt was made to correct the severest forms of valgus* In the conservatively treated group no major changes occurred At follow up valgus of 11—15 degrees was present in 111 feet (57 2 per cent) and valgus of over 15 degrees was present in 51 feet (26 2 per cent) These percentage figures are higher than those noted in the operatively treated material at follow up

At follow up of the operatively treated feet, calcaneal varus was observed in 17 feet against 27 before operation Varus of the forefoot occurred preoperatively in 57 feet and postoperatively in 50 feet In this respect therefore there had been no great improvement The severest forms had decreased in frequency, however

Conclusions

The patient is greatly benefitted by operation, since swelling, pain, and pain on weight bearing were found to disappear almost completely In addition correction of deformities was often achieved Slight or moderate valgus does not seem to cause discomfort on walking In the conservatively treated series the rheumatoid process was mostly found to progress

Marked swelling and pain in the region of the TC joint are obviously due to inflammation of the subtalar joints which involves the more proximal tissues In addition to the rheumatoid inflammation of the joint the mechanical stress to which the ligaments are subjected owing to persistent deformity has to be taken into account as an additional cause of the condition of the TC joint The slight limitation of the range of motion of the talocrural joint which occurred during the time of observation is obviously attributable to the steady progression of the disease and to the swelling caused by the mechanical stress on the TC joint

Radiological findings

The subtalar joints

Osteoporosis

In regard of osteoporosis the differences between the pre and postoperative findings were slight (Table 33) and proved to be statistically insign

ficant although a certain improvement was noted The absence of a greater change for the better seems to be due to the severity of the rheumatoid inflammation, postoperative inactivity, and the relative shortness of the time of observation

The periosteal reaction

Postoperatively 98 feet (39 per cent) showed moderate or severe periosteal reaction at the margins of the talocalcaneal joint (owing to the triple arthrodesis it was mainly the posterior margin the posterior process of the talus that could be studied) The corresponding preoperative figures were 115 feet and 40 per cent According to this a slight improvement had occurred which is attributable however to the lack of accuracy of observations made on an anchylosed joint statistically the difference is significant however For the margin of the calcaneocuboid joint the corresponding figures were 53 feet (21 3 per cent) at follow up and 50 feet (17 6 per cent) preoperatively Periosteal reaction of stages 2–4 was observed in the area of the talonavicular joint at follow up in 199 feet (80 2 per cent) and preoperatively in 209 feet (73 6 per cent)

Conclusions

No convincing evidence of postoperative periosteal growth was obtained which implies that after arthrodesis periosteal growth at the margins of the tc, CC and TN joints ceased From this the conclusion may be drawn that the periosteal changes observed in these sites were due to the rheumatoid process

Union after triple arthrodesis

The development of fusion in the different duration groups is shown in Table 35 In the under one year's duration group comprising 32 feet non union of the calcaneocuboid joint was observed in two cases and non union of the talonavicular joint in three cases The remaining joints showed either partial or complete union In the whole material non union was most frequent in the talonavicular joint (23 feet 9 3 per cent) The staple had invariably remained in position and only in two cases were slight osteolysis and a tiny sclerotic area observed round the staple

Triple arthrodesis using autogenous bone graft from the iliac crest proved to be successful except in three cases in which osteitis and sequestration occurred The use of a staple is certainly not indispensable but it aids in keeping the foot in the correct position during the stage of reconstruction

as al o does the use of a graft applied as a wedge between the talus and calcaneus, as de cribed by GRICE Obviously union would occur in the rheumatoid foot just as well without a graft but the graft prevents the calcaneus from slipping into valgus, provided that too early weight bearing is avoided According to I OND et al (1951), STRINGA (1957), and HAMMACK and ENNEKING (1960) the vascularization of the autogenous bone graft begins immediately and osteoid bars may be observed as early as the second week STRINGA (1957) reported that a graft 5 mm thick had become completely vascularized within 20--25 days The reinforcement of the bone takes a longer time however according to CHARNLEY (1951) eight weeks, and according to GRICE (1955) eight to ten weeks as observed radiologically

According to LENTZ (1955) an autoplastic bone graft does not provoke any reaction against the bone formation and under favourable conditions the graft remain vital outside the organism for about two weeks In experimental inve tigation PURANEN (1966) found that the vitality of autogenous bone grafts decreases very rapidly even within a few minutes and recommended the taking of an autogenous graft during operation, immediately before its application In the pre ent series the autogenous grafts were taken just before being used No case of aseptic necrosis of an autogenous bone graft occurred

In the author s opinion not even partial weight bearing should be allowed until four to six weeks from operation in order to avoid slipping of the calcaneus into valgus Such slipping is not prevented by the bone graft and the plaster ca t since complete union of the bone has not yet occurred in two weeks which wa the time of non weight bearing pre cribed in the pre ent cases O teoporotic bone easily yield to weight bearing A total immobilization time of eight to ten week seems to be adequate, since the o teogenesis of spongy bone is very sati factory in rheumatoid patients al o EVANS (1957) found that cancellous bone united more readily than compact bone and that o teogenesis was good when the stre s was within physiological limits

In rheumatoid as well as other inflammations the regenerative forces are strong The rate of bone regeneration has not been hi tologically investigated in rheumatoid patients but in the pre ent material union occurred within eight weeks from operation in the majority of case Some authors have immobilized their patients for ten to sixteen weeks after subtalar arthrode is In the extensive series described by WILSON et al (1965) comprising 301 triple arthrode es only even feet were immobilized for a shorter period than ten weeks Partial weight bearing was allowed an aver

a e of 7 4 weeks from operation Gnicr (19 5) who performed extra arti cular arthrode is using graft allowed partial weight bearing nine to eleven weeks after operation

Conclusions

Union occurred very satisfactorily after triple arthrodesis Non union was most frequent in the talonavicular joint and the best results were obtained in the talocalcaneal joint which always showed either partial or complete union The use of autogenous bone graft may be recommended particularly in cases of severe destruction of the joints The use of graft and staple promotes the recon struction of the foot but does not prevent the calcaneus from slipping into cal gus if weight bearing is allowed too soon From the standpoint of fusion a total period of immobili ation of eight to ten weeks is sufficient

The talocrural joint

In both the operatively and the con ervatively treated series a steady progre sion of the radiological changes of the TC joint was ob erved Hence triple arthrodesis seems to have little influence on this joint As may be seen in Table 39 in the area of the TC joint osteoporo is was ob erved in 81 7 per cent in the first duration group (under one year i e immediately after operation) The high ratio may be attributed to inactivity following operation O teoporosis improved when the patient became ambulatory but owing to progre sion of the di ease a gradual increase in ostoeporosis occurred again later The joint space became narrower and erosions gradually increased as clearly emerged at least from compari on of the two extreme duration groups

In the conservatively treated feet the disease was milder and the changes were slighter Table 12 shows that erosion progressed in both the TC joint and the striples joints which implies that the di ea e became steadily though lowly worse

The figures for the radiological changes correspond to the results on the limitation of motion of the TC joint dorsiflexion being limited to less than 10 degrees in 30 2 per cent and plantar flexion to less than 20 degrees in 47 2 per cent of the ankles examined

Marginal erosive changes were mainly responsible for the slight swelling and limitation of motion observed and for tenderness on palpation and pain on stress The number of entirely painless ankles was only 80 (27 6 per cent) which strikingly bears out the ob ervations on malleolar changes of stages 0—1

Conclusions

It appears that violent inflammation of the TC joint is relatively rare. The radiological changes steadily progress after triple arthrodesis. The most frequent signs consist of erosive malleolar changes which are due in part to RA, in part to the stress to which the ligaments are subjected.

Postoperative complications

In the present series the ratio of complications was relatively low, 8.2 per cent (24 feet). The majority of complications (6.2 per cent) consisted of haematomata and wound infection. In many cases the use of vacuum suction would appear to be indicated. HOWLAND (1964) reported complications in 16 per cent of cases. In the series described by LAINE and VAINIO (1964) comprising various orthopaedic procedures on rheumatoid patients, infections occurred in 1.4 per cent. Hence it appears that the risk of infection is somewhat greater in connection with operations involving only the foot. WILCOX et al. (1966) had 14 per cent complications, mostly superficial infections of the soft tissues, in an extensive series. In order to prevent infection particular attention has to be paid to cleaning of the leg as far up as the knee. In the presence of eczema of the leg it is advisable to protect the operative area by a sterile plastic membrane or to postpone the operation.

Operation did not activate the rheumatoid process and after a transient elevation the ESR returned to the preoperative level or to an even lower level if the patient stayed sufficiently long in the hospital. In only 23 cases (out of 267) did the temperature rise postoperatively by more than one degree, but this may be due to the fact that the patients as a rule were continuously given medical treatment for RA. After radical synovectomy, when an abundance of inflamed synovia had been removed (e.g. in synovectomy of the knee joint), LAINE and VAINIO (1964) found that a transient rise of the ESR could be followed by abatement of the general symptoms as well as of the joint symptoms. It may perhaps be suggested that a temporary improvement of the general condition results from increased adrenal function due to operative stress.

3. Do rheumatoid arthritis or triple arthrodesis cause instability of the talocrural joint?

According to many authors, deformities of the foot and triple arthrodesis affect the resistance of the ligaments to the rotational movements of the

foot which after triple arthrodesis has been carried out mainly influence the TC joint and its ligaments (SMITH and v. LACKUM 1925, HALLGRIMSSON 1943, ANDERSSON et al. 1952, BARNETT 1955, LAPIDUS 1956, WESTIN and HALL 1957, KITIGER 1958, MACKENZIE 1959, HALL 1963, 1965, WALLER 1963, WRIGHT et al. 1964). In the presence of valgus the deltoid ligament is stretched. Of particular importance are the observations made by BARNETT (1955), WALLER (1963), and WRIGHT et al. (1964) concerning the action of the TC joint in the normal foot. WRIGHT et al. stated that the normal rotation of the subtalar and ankle joints was between 6 and 14 degrees in stance phase, which may explain the progressive laxity observed to develop in the ankle joint after subtalar fusion.

In the present study lateral talar tilt of over 5 degrees was observed in 58 ankles (22.7 per cent) in the operatively treated series, in 36 ankles (18 per cent) in the conservatively treated series, and in 7 ankles (11.7 per cent) in the control group. Medial talar tilt of over 5 degrees was measured in 13 ankles (5.1 per cent) in the operatively treated series, in 4 ankles (2 per cent) in the conservatively treated series, and in no case in the control group. Accordingly, tilting was more frequent in the operatively than in the conservatively treated feet. But when the results were statistically analysed and compared to the corresponding results for the normal control, no significant differences were observed. This shows that the tilting of the talus in the rheumatoid material was of no considerable magnitude. RUBIN and WITTEN (1960) found that there was a wide variation in the normal talar tilt angle. This observation is corroborated by the present results. In respect to both lateral and medial talar tilt there was an obvious statistically significant difference between the operatively and conservatively treated series. This argues in favour of the view that triple arthrodesis affects the TC joint and its stability, and it corroborates the assumption that when the compensatory influence of the subtalar joints is eliminated the rotational movements of the foot and ankle during the course of time may cause instability of the TC joint. In this connection it should also be recalled that the movements of the talus in the osteoporotic bone were found gradually to produce slight rounding of the corners of the TC joint. Similar evidence is constituted by the atrophy of the talus and malleoli, which is obviously responsible for the »click» phenomenon attributed by MULLINS and SALLIS (1958) to broadening of the TC mortise. This phenomenon seemed to be much more obvious in the ankles operated upon than in the conservatively treated feet. According to GRATH (1960), even an intact deltoid ligament allows lateral movement of 2 mm.

In the present study lateral talar tilt of over 5 degrees was observed in 20 feet (31 3 per cent) in maximal plantar flexion which was clearly more often (the difference is highly significant) than in the ankles examined in mid position From this the conclusion may be drawn that the anterior talofibular ligament was more worn out and weaker than the calcaneofibular ligament since in plantar flexion the anterior talofibular ligament is subjected to greater stress, while in mid position the stress mainly falls on the calcaneofibular ligament The e features of the anatomical structure and function of the lateral ligaments have been described by many authors e g DEHNE (1933) LEONARD (1949), ANDERSSON et al (1952), BROSTROM (1964), and NEVIN and POST (1964) In the pre ent series of operatively treated feet anterior subluxation of the talus was only observed in 14 cases (26 4 per cent) The corre ponding figures in the conservatively treated series were 13 cases and 19 1 per cent The difference is statistically insignificant Hence the conclusion may be drawn that the operation had not injured the anterior talofibular ligament The frequency of subluxation shows a fairly good correspondence with the frequency of lateral talar tilt of over 5 degrees in both the operatively and non-operatively treated series

At follow up tilting of the talus on both the lateral and the medial a pect was found to correlate with narrowing of the TC joint space (Table 48) in both series A decrease in the tilting angle was coincident with obvious (stage 2) narrowing of the TC joint space A very obviou decrea e correlated with further narrowing and in the group showing narrowing of stage 4 there were only two operated ankles in which lateral and medial talar tilt of 1—5 degrees was measured, and two conservatively treated ankles with lateral talar tilt of 1—10 degrees but no medial tilting The decrease in talar tilt clearly appears from Tables 44—45, in which the material is presented according to duration groups Irrespective of the presence of planovalgus medial talar tilt seemed to be less pronounced than lateral tilting This is probably due to the anatomical structure of the ligaments, the deltoid ligament being markedly stronger than the lateral ligaments

Conclusions

On comparing the postoperative results with the follow up results on the conservatively treated feet it appeared that triple arthrodesis seems to cause an increase in talar tilting This is obviously due to the elimination of the compensatory influence of the subtalar joints, as a result of which the rotational movements of the foot are reflected in the talocrural joint Rheumatoid arthritis

and secondary inflammatory changes weaken or may even destroy the ligaments of the ankle but at the same time the disease gradually although very slowly leads to narrowing of the talocrural joint space and fibrosis of the tissue which counteract tilting of the talus and stabilize the talocrural joint The presence of instability does not depend solely on the occurrence of talar tilt it is also influenced by muscular tonus Nearly always the muscular functions of the rheumatoid patient are well preserved slight talar tilt does not cause instability on walking *The talar tilt resulting from triple arthrodesis does not essentially contribute to instability of the talocrural joint in rheumatoid patients*

4 Does arthrodesis of the subtalar and midtarsal joints lead to the development of osteoarthrosis in the talocrural joint?

Many previous investigators have mentioned the development of osteoarthrosis of the talocrural joint as a complication to arthrodesis of the subtalar joints (HART 1937, BENTZON et al 1949 LEIKKONEN 1950 after astragalectomy, MACKENZIE 1959 after LAMBRINUDI s operation ROBINS 1959 LINDHOLM 1960, HOWLAND 1964 RUGTVEIT 1964 WILSON et al 1965) In the majority of cases in these series poliomyelitic or other paralytic conditions constituted the indication for operation LAMBRINUDI s operation or astragalectomy as described by WHITMAN have often been performed when the muscular balance of the leg has been disturbed After a long observation period ROBINS observed slight rounding of the margins of the talus only in a few cases Degenerative changes were not present provided that varus and valgus deformities had been adequately corrected In HOWLAND s series only one patient showed arthrosis of the TC joint and RUGTVEIT observed no such case WILSON et al do not mention osteoarthrosis of the TC joint or discomfort caused by this condition

In the present study osteoarthrosis of the TC joint was observed preoperatively in 36 cases (12 7 per cent) and at follow up in 70 cases (28 2 per cent) At corresponding points of time this condition was found in the conservatively treated series in 21 cases (10 3 per cent) and 36 cases (21 2 per cent) Osteoarthrosis thus seemed to occur somewhat more frequently in the operatively treated feet In both series the rheumatoid changes showed about the same pattern of increase The development of osteoarthrosis seems to be secondary to the inflammation of the joint It seems possible that the greater frequency of osteoarthrosis in the operatively treated series is attributable to the talar tilt which sometimes was a result of triple arthrodesis

In cases of old standing rounding of the corners of the talar horizontal joint and the corresponding points of the tibia and fibula was occasionally observed This change may also be caused by the rheumatoid destructive process

Conclusions

Osteoarthrosis of the talocrural joint seems to increase with progression of rheumatoid arthritis When the operatively treated feet were compared to the conservatively treated group from the standpoint of the development of osteoarthrosis of the talocrural joint the change that occurred from a point of time prior to operation until follow-up examination seemed to be somewhat greater in the operatively treated series The cause of this may perhaps be that the joint in question is subjected to greater stress in feet on which triple arthrodesis has been performed

5 What are the functional results of operative treatment?

The operative result was good in 218 feet (85 5 per cent) fair in 25 feet (8 6 per cent) and poor in 17 feet (5 9 per cent) In a total of 12 feet (38 patients) obvious functional defects remained, and the patients were not quite satisfied with the result In many cases severe planovalgus, with calcaneal valgus of over 15 degrees caused discomfort Moderate calcaneovarus and severe varus of the forefoot also seemed to cause discomfort No patient complained that the TC joint gave way but they experienced discomfort on walking due to this joint which had remained painful

Triple arthrodesis was performed on both feet in 63 cases The functional result was not quite satisfactory in both feet in four patients and in one foot in eight patients These 16 feet constitute 12 7 per cent of the total number of double arthrodeses (126 feet) This does not indicate any increased risk of complications from bilateral triple arthrodesis when the two feet are operated upon at different times

Of the deformities varus (calcaneovarus in particular) seems to be the most harmful but calcaneovalgus of over 15 degrees should also be avoided The patients do not seem to mind moderate valgus as long as there is no pain However moderate valgus makes it necessary to wear a support in the shoe The ideal seems to be when the calcaneus is in the normal anatomical position

Painful non union occurred in only three feet non union of the Chopart joint in two feet and non union of the TN joint in one foot (the total number of joints showing painful non union being thus five) Non union was

observed in a total of 39 joints (23 TN joints and 16 CC joints) It thus appears that non union seldom causes major discomfort Obviously the absence of untoward effects is due to the presence of fibrous anchylosis which prevents painful movement In all the above mentioned three cases a disturbing varus deformity was present It is evident that the non union was due to poor bony contact and led to varus

According to HALLGRIMS ON (1943) PATTERSON et al (1950) HOWLAND (1961) and WILSON et al (1965) pseudarthrosis most often occurs in the talonavicular joint In the most extensive series followed up (including, in addition to the above mentioned those described by SMITH and VON LACKUM 1955, LINDHOLM 1960 and POLLOCK and CARRELL 1964) the proportion of poor results varied between 6 and 15 per cent Consequently the results of triple arthrodesis performed on account of rheumatoid arthritis can well be compared with those of subtalar arthrodesis carried out on other indications

Conclusions

Rheumatoid patients derive considerable benefit from triple arthrodesis for the following reasons 1) Pain is relieved in the most important joints of the foot and the clinical symptoms of the talocrural joint are at least transiently diminished 2) The operation stabilizes the foot and prevents aggravation of deformities At the same time deformities may be corrected or their ill effects may be reduced It is advisable, however to perform the operation within three years from the onset of steadily progressing symptoms Attention should be attached to correct positioning of the calcaneus, the ideal being the normal anatomical position In any event varus is to be avoided The forefoot should be placed in plantegrade position and quite frequently there is a varus deformity requiring correction 3) Even though subtalar motion is lacking if the foot is painless and in good or satisfactory position the TC joint causes relatively little discomfort 4) The functional results observed in the present study were even better than those reported in other series

6 What is the most favourable time for the performance of triple arthrodesis from the standpoint of the development of the disease and the best possible result?

On the basis of the present study it may be stated that the most favourable time for triple arthrodesis can be determined by following the development of the following signs *1) Swelling pain at rest and on motion (the first clinical signs) 2) Planovalgus 3) Osteoporosis particularly in the surround*

ings of the calcaneocuboid joint 4) Joint space narrowing, particularly in the talonavicular joint These signs develop rapidly within three years and are thus early signs 5) Erosions This sign is first discernible in the talonavicular joint (in 11 9 per cent of cases in the under three years duration group) During the first three years of the disease the medial and lateral aspects of the talocrural joint showed clearly less erosions than the subtalar joints For this reason evaluation of the prognosis of the disease and of the best time for the performance of triple arthrodesis cannot be based on the occurrence of erosions in the talocrural joint This sign must first be looked for in the talonavicular joint, then in the calcaneocuboid and talocalcaneal joints

If the talocrural joint is destroyed showing surface erosion of at least stage 2 and the joint is painful on motion, there is reason for considering the performance of pantalar arthrodesis If synovial hyperplasia of the talocrural joint is suspected and the joint does not yet show definite surface erosions it is the author s opinion that synovectomy of the talocrural joint performed in addition to triple arthrodesis, is a beneficial procedure which slows down the rheumatoid process

Conclusions

The most favourable time for the performance of triple arthrodesis depends on the above-mentioned symptoms It is advisable to operate before the development of severe deformities and destructive changes

X SUMMARY

The present study is concerned with the changes in the pantalar joints caused by rheumatoid arthritis and the significance of arthrodesis of the subtalar joints (triple arthrodesis) from the standpoint of the rheumatoid patient Furthermore the effects of rheumatoid inflammation and of triple arthrodesis on the stability of the talocrural joint were investigated by a special radiological method

The material consisted of two series feet on which triple arthrodesis was performed (292) and feet which were conservatively treated (204) The majority of cases (290 operatively treated and 191 conservatively treated feet) were followed up The average follow up period was 3 6 years

The various points investigated are specified in the part headed Problems and in connection with the detailed discussion of the results

The investigated feet belonged to patients who were treated at the Hospital of the Rheuma Foundation Heinola during the years 1953—1961

Preoperative study

Clinical symptoms and signs

Marked swelling pain on motion and limitation of the range of motion were found to be typical features The last mentioned symptom progressed rather slowly Preoperatively swelling of the area of the subtalar joints was observed in 98 3 per cent of cases pain on motion in 98 6 per cent Pain at rest was less common being observed in 62 3 per cent Limitation of the range of subtalar motion was noted in 96 6 per cent The development of anchylosis of the subtalar joints was found to take a long time since both pronation and supination were entirely lacking in only two feet The dorsal flexion of the talocrural joint was 15 degrees or less in 79 8 per cent of cases and the plantar flexion was under 40 degrees in 78 4 per cent Motion of the

(24 4 per cent) The range of motion of the TC joint was only slightly limited which may be attributable to progression of the disease and not to the triple arthrodesis Moderate or marked pain was present in only 48 TC joints (16 5 per cent)

Postoperatively the foot became practically painless and the symptoms in the area of the TC joint were also alleviated although they persisted in some cases

A noteworthy result of operation was the partial correction of planovalgus deformities the severest calcaneovalgus positions (over 15 degrees) showing a marked decrease in frequency Preoperatively valgus of over 15 degrees was observed in 128 feet (43 8 per cent) at follow up in 66 feet (22 8 per cent) In the conservatively treated series no major changes occurred during a corresponding period of time, probably the deformities had become fixed Calcaneovarus and varus of the forefoot had decreased, but calcaneovarus was still present in 17 feet varus of the forefoot in 50 feet The deformities causing the greatest discomfort were calcaneovarus severe calcaneovalgus, and varus of the forefoot These have to be corrected in order to attain a satisfactory result The present anatomical results were good in 142 feet (48 9 per cent), fair in 114 feet (39 3 per cent), and poor in 34 feet (11 8 per cent)

Radiological findings

Osteoporosis and periosteal reaction in the subtalar region

Moderate or severe osteoporosis in the area of the anchylosed joints occurred in an average of 72 0 per cent of cases which means that a slight improvement had occurred as a result of increased use of the foot and subsiding of the rheumatoid process The development of the periosteal changes was arrested by the operation In the area of the talocalcaneal joint these changes even showed a slight decrease From this the conclusion may be drawn that the periosteal changes were due to the rheumatoid process

Radiological changes in the talocrural joint

The severest osteoporosis of the TC joint was observed in the years immediately following triple arthrodesis Subsequently a slow improvement occurred but after seven years duration the effect of RA became noticeable as a gradual increase in osteoporosis The TC joint space showed narrowing in 74 cases (29 8 per cent) and erosion showed a steady increase as compared with the preoperative state On this point the difference was

highly significant. At follow up surface erosions were observed in 90 ankles (36.3 per cent), erosions of the medial part of the mortise were observed in 180 ankles (72.6 per cent) and erosions of the lateral part of the mortise in 165 ankles (66.5 per cent). Erosions of the medial part were thus clearly more frequent than erosions of the lateral part. Obviously valgus deformity causes heavier stress on the medial aspect via the deltoid ligament in particular following subtalar arthrodesis, when the rotational movements of the foot most strongly act upon the TC joint. It seems possible that under the influence of stress erosions more readily develop in a cartilaginous surface affected by RA. Osteoarthrosis of the TC joint showed a somewhat greater increase in the operatively treated group than in the conservatively treated ankle, and the aggravation was more marked than was to be expected on the basis of the exacerbation of the rheumatoid changes. Arthrosis of the TC joint was observed in 70 feet (28.2 per cent) in the operatively treated series and in 36 feet (21.2 per cent) in the conservatively treated series. The fact that the frequency was somewhat higher than expected in the operatively treated series may be accounted for by the effect of triple arthrodesis and the resulting stress on the TC mortise. In the conservatively treated series the radiological changes in both the subtalar joints and the TC joint showed an obvious aggravation when the observations made at different points of time were compared.

Instability of the talocrural joint

In order to assess instability of the talocrural joint, the talar tilt angle was measured on radiographs taken at stress examinations. Three groups were compared: feet on which triple arthrodesis had been performed, conservatively treated feet, and normal feet. On comparison of the normal group and the rheumatoid feet no significant difference emerged in respect to either medial or lateral tilting. But after triple arthrodesis the talus tilted significantly more than in the conservatively treated ankles. It appears that in the absence of the balancing influence of the subtalar joints the ligaments of the TC joint are subjected to heavier stress than before, resulting in degeneration and decrease of the tensile strength of these ligaments. The lateral ligaments were surgically explored in 43 feet. It was found that in addition to destruction of the ligaments, RA caused fibrosity of the tissues and gradually led to narrowing of the joint spaces and anchylosis. For this reason no large talar tilt angles can develop and thus no clinical instability appears on normal walking. A lateral talar tilt angle of over 5 degrees was

measured in 58 ankles (22 7 per cent) in the operatively treated series and in 36 ankles (18 0 per cent) in the conservatively treated series A medial talar tilt angle of over 5 degrees was observed in the former series in 13 ankles (5 1 per cent), and in the latter series in only 4 ankles (2 0 per cent) Anterior subluxation of the talus was observed on stress examination in only 14 (26 4 per cent) of the operatively treated feet thus examined and in 13 (19 1 per cent) of the conservatively treated feet Statistically the difference between these two figures is insignificant

Osteoarthrosis of the talocrural joint as a complication of triple arthrodesis

At follow up examination rounding of the joint surface of the talus and the mortise was observed in some cases Osteoarthrosis was found to develop as a secondary phenomenon *following the rheumatoid change* and *to* progress with prolongation of the disease The result is anchylosis of the joint, and no new joint develops by regeneration As already mentioned above, *after triple arthrodesis osteoarthrosis seemed to develop* somewhat more rapidly than did the rheumatoid changes and this appears to be due to the greater stress to which the TC joint is exposed and to pseudoinstability. *This is of no practical significance to the patient*

Functional results

On evaluation of the operative results the patient's own opinion concerning *the function of the foot* was *taken into* account, in addition to the possible presence of anatomical deformities or other factors causing discomfort The result was good in 218 feet (85 5 per cent), fair in 25 feet (8 6 per cent) and poor in 17 feet (5 9 per cent)

The causes of partial failure were the following severe or extreme plano valgus in 17 feet (5 9 per cent), moderate or severe pes varus or calcaneo varus in 10 feet (3 4 per cent) severe varus of the forefoot in 6 feet (2 1 per cent) decrease of function or severe pain in the talocrural joint in 4 feet (1 4 per cent) other causes (infection, pseudarthrosis RA of the other non operated joints of the foot) in 5 feet (1 7 per cent) Triple arthrodesis was performed on both feet of 63 patients but at different times This did not increase the frequency of complications

The majority of the patients were satisfied with the results of operation although in many cases calcaneovalgus of 10—15 degrees remained The *patients attached great value to being able to step on a relatively painless* stable foot Pseudarthroses were rare and painful non union was present in

only three feet. A total of 39 joints, i.e. 23 TN and 16 CC joints, showed non-union. The talocalcaneal joint showed partial or complete union in all cases.

Triple arthrodesis resulted in an almost painless ankle in a better position than preoperatively. The operation ought to be performed before persistent planovalgus or varus deformities have developed, according to the present result within three years from the onset of steadily progressing symptoms in the ankle. In this series triple arthrodesis was almost invariably carried out by RYERSON's method using bone graft (GRICE 1952) and chips (VAINIO's modification) between the talus and calcaneus. The graft, however, does not prevent the calcaneus from slipping into valgus if weight bearing is allowed too soon, and a good plaster cast is not sufficient protection against this, either. Hence the period of non-weight bearing ought to be a minimum of four to six weeks and the total time in plaster about eight to ten weeks. Obviously, the use of a graft is not indispensable in all cases, since union of spongy bone occurs very satisfactorily in rheumatoid patients also. But by the application of a graft and staple the calcaneus is more readily kept in the right position. With a view to correcting deformities particular attention should be paid to placing the foot in the correct position and to adequate modelling of the plaster cast.

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RADIOGRAPHS

Plates 8–17

GÖSTA FRYKMAN

FRACTURE OF THE DISTAL RADIUS INCLUDING SEQUELAE — SHOULDER-HAND-FINGER SYNDROME, DISTURBANCE IN THE DISTAL RADIO-ULNAR JOINT AND IMPAIRMENT OF NERVE FUNCTION

A clinical and experimental study



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ACTA ORTHOPAEDICA SCANDINAVICA

SUPPLEMENTUM NO 108

From th D partment f Bon nd Joint Surgery (H d. Prof ssor Erik Moberg M D) (clin cal investigation)
and the Biomechanical Laborat ry t th Dep rtment f Orthop edic Surgery
(H d Professo Carl Hirsch, M.D) (perim tal investig tion) U ersity of Göteborg, Sweden

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ERRATA

Page 11 Line 11 Hahleyss *should read* Kahleyss
Page 11 Line 14 Lindstrom *should read* Lidstrom
Page 48 Line 1 Older Stabler & Cassebaum *should read* Older Stabler & Cassebaum 1965
Page 56 Line 15 on both counts *should read* on all three counts
Page 62 Line 2 from below in contrast to the results for *should read* to the same extent as in
Page 86 Line 16 just *should read* especially
Page 98 Line 6 from below 58 *should read* 59
Page 104 Line 5 Lind trom *should read* Lidstrom
Page 104 Line 3 from below 10 % *should read* 20 %
Page 106 Line 2 15 6 % *should read* 5 6 %
Page 127 Line 21 Carlberg *should read* Calberg
Page 140 Line 6 Sudeck s atrophy *should read* Sudeck s syndrome
Page 141 Line 10 from below Chapter IX *should read* Chapter XI

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From the Department of Bone and Joint Surgery (Head Professor Erik Moberg M.D.) (clinical investigation)
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By

GÖSTA FRYKMAN

MUNKSGAARD

Copenhagen 1967

Translated from Swedish

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Patrick Hort

GÖTEBORG 1967
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CONTENTS

INTRODUCTION

The clinical picture and late results of distal fractures of the radius have recently in Sweden been discussed by Lidstrom (1959) Certain aspects however seem to me to call for further consideration The series which I chose for this purpose represents somewhat different forms of treatment while some of the examination techniques employed are also new This has facilitated a more thorough penetration of the aspects in question and is expected to lead to better end results and more satisfactory treatment of the sequelae

The aim of my study is therefore to use a clinical and statistical analysis of a consecutive series of distal radius fractures including the functional end results to try to establish the incidence and degree of such sequelae as disturbance in the distal radio ulnar joint nerve lesions shoulder hand finger syndrome and subcutaneous tendon rupture I also aim at investigating to what extent the treatment employed has been able to prevent the development of such sequelae

The study also includes a biomechanical investigation the aim of which is to study whether different types of violence are able to reproduce clinical types of distal radius fractures These experiments are intended to provide an indication of the amount of force required to produce the fracture and to show which factors apart from the force are responsible for a fracture arising

CHAPTER I

ANATOMY

The distal end of the radius is formed of cancellous bone covered by a fairly thin cortical layer that attains its minimum thickness a few centimetres proximally in the metaphysis. The distal end of the ulna has a similar structure. The radius presents two articular surfaces at its distal end, one being the carpal articular surface—comprising two concave surfaces for articulation with the scaphoid and lunate bones—and the other the ulnar notch for radial articulation with the head of the ulna. This is in fact the only direct bony articulation involving the head of the ulna.

Both the radio carpal and the radio ulnar joint have relatively thin and slack capsules but these are reinforced by several ligaments. They lie close to the borders of the articular surfaces on the radius and ulna, the articular disc

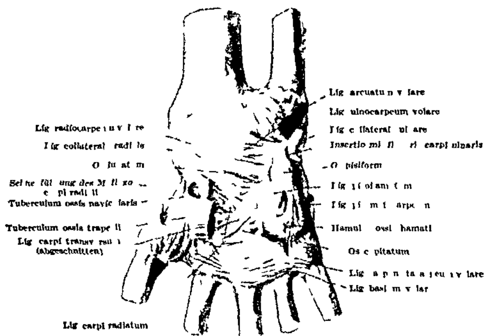


Fig. 1. Volar aspect of the wrist. After von Lanz & Wachsmuth (1959)

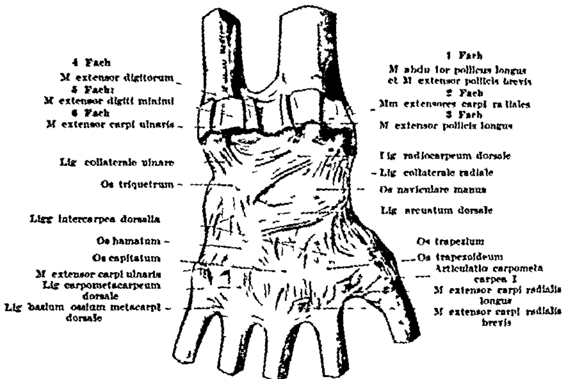


Fig 2 Dorsal aspect of the wrist After von Lanz & Wachsmuth (1959)

and the carpal bones the radio carpal capsule is reinforced by ligaments running distally from both the radius and the ulna while ligaments also run between the distal ends of these bones

There is a collateral ligament attached to the styloid process of the radius and another attached to the styloid process of the ulna (cf Figs 1 and 2) The former is short and strong extending to the scaphoid bone the latter is longer but weaker and fixes to the triquetral and pisiform bones The dorsal and volar ligaments to the central part of the carpus issue mainly from the distal part of the radius only the volar ones occur regularly (von Lanz & Wachsmuth 1959) The dorsal radio carpal ligament which is not always present is largely fixed to the triquetral bone a few fibres running to the lunate and scaphoid bones the volar radio carpal ligament which is constantly found has a strong band attaching to the scaphoid and triquetral bones while weaker fibres extend to the capitate bone From the styloid process on the ulna the corresponding structure or volar ulnar carpal ligament combines with the volar radio carpal ligament to form an arch shaped band sometimes known as the volar arcuate ligament which runs in a loop round the head of

the capitate bone and round the lunate bone A dorsal ulnar carpal ligament does not occur regularly

The distal radio ulnar joint is reinforced by transverse bands forming the volar and dorsal radio-ulnar ligaments which are not particularly strong They intermingle along the border of the articular disc but are separated proximally by a synovial pouch (*recessu sacciformis*) that runs up between the radius and the ulna (cf Fig 3)

The broad base of the articular disc in the distal radio ulnar joint attaches to the distal edge of the ulnar notch on the radius from where the disc converges onto its insertion on the ulnar styloid process The distal surface of the disc accounts for about one quarter of the proximal articular surface of the radio carpal joint the other three quarters being formed by the radius In shape the disc resembles an equilateral triangle Its insertion on the ulna may vary Schinz (1922) has described two sites one more radially on the head of the ulna the other at the tip of the styloid process a further variant is a twin insertion at the foot and tip of the ulnar styloid process

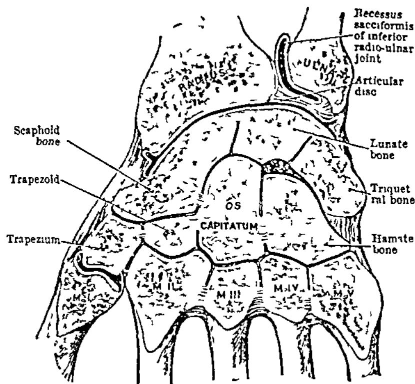


Fig 3 Coronal section through the radiocarpal carpal carpometacarpal and intermetacarpal joints to show joint cavities and interosseous ligaments (diagrammatic) After *Cunningham s Anatomy* (1943)

The disc is quite frequently perforated at its insertion on the ulnar notch of the radius thereby connecting the radio carpal and radio ulnar joint cavities The incidence of this communication is reported to be about 25 % (von Lanz & Wachsmuth, 1935) The degenerative changes in the disc increase with age, frequently leading to a perforation in the middle of the disc as well (Lang 1942 von Lanz & Wachsmuth, 1959)

In addition to the ligaments described above attention should be drawn to the following soft tissues in the vicinity of the carpal bones the pronator quadratus muscle the volar and dorsal carpal ligaments and the transverse carpal ligament which lies distal of the volar carpal ligament Nor should one forget the tendons nerves and vessels in the volar and dorsal parts of the carpal region these may incur a variety of injuries in conjunction with or following fracture of the radius The extensor tendons thus lie dorsally in their tunnels deep to the extensor retinaculum while the flexor tendons are to some extent protected from the usual site of fracture by the pronator quadratus muscle

The median nerve and the flexor tendons run in the carpal tunnel The nerve may be exposed to various types of injury as a result of constriction when the distal radius fractures Anatomically the ulnar nerve and artery are less vulnerable than the median nerve since they lie under superficial parts of the volar carpal ligament on the radial side of the flexor carpi ulnaris muscle which affords them some protection They may nevertheless be in danger when the distal radius and ulna are fractured, partly because the volar carpal ligament inserts on the ulna

The pronator quadratus muscle finally has a stabilizing effect on the distal radio ulnar joint as have the interosseous membrane the articular capsule in the distal radio ulnar joint the volar and dorsal radio ulnar ligaments the triangular disc, the ulnar carpal ligament and the dorsal and volar superficial carpal ligaments

CHAPTER II

MECHANISM OF INJURY

Fracture of the distal part of the radius is generally thought to be caused by a fall onto the outstretched arm the hand being in dorsal flexion or volar flexion to break the fall Depending on the position of the hand at the time the fracture will involve dorsal or volar displacement of the distal fragment (i e Colles or Smith s fracture respectively) This simple conception of the mechanism of injury appears to be the one most widely accepted in the literature possibly because the considerable effort devoted to this question has failed to produce any more definitive account

In studying the mechanism of injury, many authors have based their theories on experiments with cadavers (Nelaton 1844 Lecomte 1861 Honigschmied 1878 Hahleyss 1897 Roberts 1897 Cotton 1900 Rosenbach 1902 Lilienfeldt 1907 1908 Pilcher 1917 Kleinschmith 1929 Mayer, 1940 Lewis, 1950) In general however they do not seem to have produced any very remarkable findings though Lilienfeldt is an exception As Lindström (1959) points out, Lilienfeldt s (1907 1908) results have to some extent shaped the accepted conception of the fracture mechanism in wrist injuries He demonstrated that the type of injury could be varied at will by manipulating two factors namely the position of the hand and the angle between the forearm and the surface of impact Lilienfeldt s experimental design was extremely simple The specimen was exarticulated at the shoulder and suspended in such a way that the position of the hand and forearm could be adjusted In each position the investigator fell onto the arm with the weight of his body With this technique, Lilienfeldt was able to produce fractures of the distal radius provided that the angle between the forearm and the surface of impact was between 60° and 90 If at the same time the hand was in ulnar deviation the fracture ran through the radial styloid process whereas the ulnar styloid process fractured if the hand was in radial deviation Lilienfeldt managed to reproduce a Smith fracture in one case the trauma being directed against the back of the hand from this he concluded that the dislocation is a direct result of the direction of the traumatic force The scaphoid bone fractured if the angle between the forearm and the surface of impact was at least 90° and the hand was in dorsal flexion and radial deviation Radial deviation see

CHAPTER III

BIOMECHANICAL INVESTIGATIONS

As mentioned in the last chapter, numerous studies have been published concerning the experimental production of fractures in the distal radius Various techniques have been employed As a rule the aim has simply been to reproduce the type of fracture met with in clinical practice without specifically studying the forces required to produce the fracture The results generally show that a particular technique was successful in producing such types of fracture but only in a limited proportion of the series

The incompleteness of earlier series of fracture experiments seems to have been remedied to a considerable extent by the use of special apparatus This has been demonstrated in recent years for experimentally produced fractures of the neck of the femur (C Hirsch & Frankel 1960) of the calcaneum (Thorén 1964) of the knee joint (G Hirsch & Sullivan 1965) and of the ankle joint (C Hirsch & Lewis 1965) The results published by these authors were obtained with two types of biomechanical fracture investigations All except Thorén employed a *static* variant and determined the fracture resulting from a known controllable force (kp) The experiments were made with a hydraulic apparatus (Amsler universal testing machine) to which an automatic writer was attached giving the size of the load in kp Thorén s study on the other hand, involved *dynamic* experiments to determine the fracture resulting from varying degrees of external violence (amount of energy) The apparatus used was an Amsler pendulum type impact machine strain gauges fitted to the head of the pendulum and connected to an oscilloscope made it possible to obtain a photographic record of the forces occurring at the moment of fracture

No such biomechanical fracture experiments have been published for the distal radius Consequently it seemed well worth conducting a series of experiments with these two types of apparatus with the aim of reproducing distal fractures of the radius in forearm specimens under static and dynamic loading Such experiments should indicate the amount of the forces producing the fracture and might also indicate suitable conditions for reproducing clinical types of distal radius fractures with greater regularity than has been achieved in previous investigations

The size of a biomechanical experimental series of this type will naturally be limited by the relative scarcity of forearm specimens The uneven supply of such specimens led to the dynamic series of experiments being smaller than the static in the present study This must of course be born in mind when assessing the results

Specimens

The forearm specimens used in the experiments came from autopsies and surgical operations on 23 women and 25 men In the majority (36) of the 48 specimens the forearm had been resected just below the elbow in the other 12 it had been resected about 10 cm above the wrist Two of the women from whom the specimens came were 46 and 56 years old respectively all the others were between 65 and 78 years Most of the men were between 58 and 79 years though five specimens came from men aged 19–50 years None of the above persons had skeletal diseases involving the forearm or hand nor had they any roentgenological signs of osteoporosis

Distal fractures of the radius were produced in 32 of the 48 experiments (Details of these 32 are given in Table 1 at the end of this chapter)

The specimens were either used the same day as they were resected or else stored at −20 C until the day of the experiment when they were thawed at room temperature In both the static and the dynamic experiments the specimen was first freed from soft tissue within a region of about 5 cm from the proximal end after which the fatty tissue in this region was also removed The prepared specimen could then be fixed in a metal holder (C Hirsch 1964) with the aid of a cast compound (Plastic Padding) that hardened at room temperature the forearm being held vertical

Apparatus

Static experiments were conducted with an *Amsler universal testing machine* A kymograph coupled to this machine recorded the size of the load in kp during the course of the experiment together with changes in the distance between the ends of the specimen The testing machine is hydraulically powered and can generate a constant rate of loading In the present experiments this rate was ca 100 kp/min The metal holder into which the specimen had been cast was fixed to the loading head of the machine as indicated in Fig 4 The specimen thus hung vertically the palm resting against a wooden block placed on the machine s supporting head Several different wooden blocks were used in the experiments their upper surface sloping at different angles This made it possible to vary the angle of the wrist as required In the earliest experiments the hand was screwed onto the

CHAPTER III

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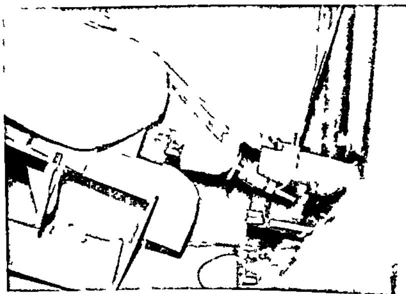


Fig 5 The apparatus used in the dynamic experiments

In the second series of dynamic experiments equipment ... measuring and recording the force of impact of the ... Fig 6) The part of the pendulum (9) carrying the ... delivers the blow to the specimen (5) was designed as a ... tube To this were attached four strain gauges ... long screened cable to a balancing unit (3) The ... led to the y axis amplifier of an oscilloscope (2) T... calibrated by subjecting the pendulum head (8) to a k... the deflection on the y axis of the oscilloscope The ... was coupled to a variable time generator The ... by a special signal from a triggering unit (1) co... switch (7) The microswitch was placed so that ... seconds before the impact plate reached the spe... time generator had started when the blow fell ... defined zero level for the measurements

With this apparatus the curve of the impact f... in ms) could be read directly from the oscillosc... with a Polaroid camera attached to the oscillos... was facilitated by introducing a screen throug... ratus had a total error of measurement of ± 1... on the y axis and ± 0 5 ms at 10 ms max d...

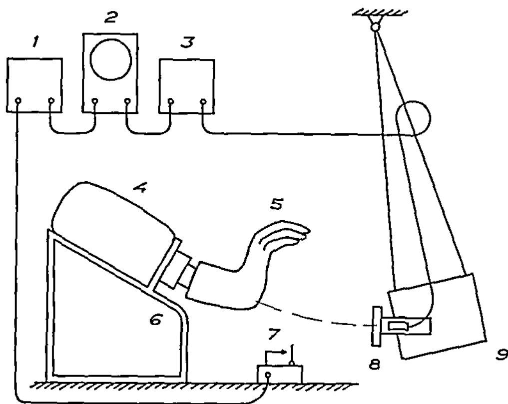


Fig 6 The experimental set up of the second series of dynamic experiments 1 Triggering unit 2 Oscilloscope 3 Balancing unit 4 Counter weight on specimen stand 5 Specimen 6 Specimen stand 7 Trigger 8 Impact force gauge 9 Pendulum

In both the static and the dynamic experiments x rays were first taken of *the wrist of the specimen in two projections This was also done immediately* after each experiment The specimen was then dissected and photographs were taken of the exposed fracture

Results of static experiments

A total of 37 static fracture experiments were performed clinical types of distal radius fractures being obtained in 22 The other 15 experiments produced the following injuries fracture of proximal radius ulna (5) proximal radius fracture and distal ulnar dislocation (2) proximal radius fracture (1) distal ulna fracture (1) scaphoid fracture (2) scaphoid and capitate fracture (1) *pisiform hamate and capitate fracture* (1) *triquetral fracture* (1) and volar dislocation of the lunate bone with volar fracture in this (1)

The following account is mainly concerned with the fractures of the distal radius obtained in this series.

The 23 experimental fractures of the distal radius classified in the same way as in the following series (cf. Chapter IV p. 31) comprised the following types (I–VIII):

I	II	III	IV	V	VI	VII	VIII
–	1	2	—	–	—	[illegible]	4

No less than 15 of them were extra-articular fractures. [illegible] were also accompanied by a [illegible] in the [illegible] of the [illegible] (f. [illegible]. In [illegible] the fracture [illegible] in the distal radio-ulnar joint was also found in [illegible] of the 15 specimens. In [illegible] of these the fracture was [illegible] in the [illegible]. One specimen with a [illegible] extra-articular fracture in the radio-ulnar joint also had a ruptured radial collateral ligament.

X-rays of different types of fractures obtained in these experiments are reproduced in Figs. [illegible]–13. The fracture shown in Fig. 13 was produced in one of the dynamic experiments.

Only fractures with [illegible] displacement were obtained in the [illegible] experiments, [illegible] because [illegible] the distal fragment [illegible] [illegible] which were applied in this series.

The tensile strength of the [illegible] did not differ markedly between specimens taken from individuals of different ages but the same sex. A clear difference was found, on the other hand, between the tensile strengths of distal radius in specimens from men compared with women. The strength in the male specimens ranged from [illegible] to [illegible] kp, mean [illegible], and in the female specimens ranged from [illegible] to [illegible], mean [illegible] (see Table [illegible]). It may be noted that under similar experimental conditions no essential difference in tensile strength was found between the short and the long specimens. Nor was there any difference in the types of fracture produced that could be ascribed to the length of the specimens.

Distal fractures of the radius were obtained in this static series when the specimen was loaded with the wrist in [illegible]–[illegible] dorsal flexion and [illegible] radial or ulnar deviation. In general it seems that the greater the degree of dorsal flexion, the larger the force required to produce a fracture.

With more than [illegible] dorsal flexion of the wrist, however, injuries occurred in the carpal bones (see above), usually involving the scaphoid bone. Fracture of the scaphoid alone was obtained only when the hand was also in radial deviation; multiple injuries of the carpal bones occurred when the hand was midway between radial and ulnar deviation or else in ulnar deviation. Injuries to the carpal skeleton also accompanied four of the fractures in the distal radius, [illegible] the scaphoid bone in one experiment, multiple carpal

injuries in the other three) In these four experiments the course of events followed a particular sequence The fracture in the distal radius seemed to occur first followed by the injury to the carpal bones as the dorsal bending of the specimen increased before the loading could be discontinued The lateral angulation of the hand in these experiments also resembled the conditions that seemed to apply in other experiments in which carpal injuries occurred without fracture of the distal radius

The loads which led to carpal injuries—from 265 and 510 kp (mean 396 kp)—were considerably higher than those which produced fractures of the distal radius Furthermore the loads which resulted in a combination of distal radius fracture and carpal injuries were generally higher than those which produced a distal radius fracture alone

As already mentioned eight of the static experiments resulted in proximal fractures in the radius and ulna or only in the radius in one case combined with distal dislocation of the ulna Although these experiments did not result in the type of fracture aimed at certain features seem worth mentioning here They started in the same way as all the other static experiments—with the specimen resting against a wooden block the surface of which sloped to varying degrees thereby producing a dorsal flexion of 40–70 in the wrist Loading of the specimen caused the block—and hence the hand—to slide with the result that the angle between the forearm and the hand gradually straightened out When the dorsal flexion in the wrist had dropped to 20–35 the proximal forearm fractures arose at loads between 60 and 190 kp (mean 120 kp) This is considerably less than the loads at which distal radius fractures occurred in the static series

Discussion The results of the static fracture experiments seem to justify the following conclusions

(1) Clinical types of distal radius fractures can be obtained with great regularity on static loading provided the dorsal flexion in the wrist is not less than 40° and not more than 90°

(2) The degree of dorsal flexion in the wrist also seems to be related to the occurrence of fractures in the carpal bones and in the proximal forearm Fractures of the carpal bones occurred when the dorsal flexion in the wrist was more than 90° proximal forearm fractures when it was less than 40°

(3) Considerable force appears to be required to produce a distal fracture of the radius The force required would seem to be related to the degree of dorsal flexion in the wrist since less force produced a fracture when the dorsal flexion was relatively slight Another finding in keeping with this observation is that all the proximal forearm fractures in the series occurred at a lower load than the distal radius fractures at the same time as the dorsal flexion of the wrist in the former was less than 40° Furthermore the carpal bone fractures in this series occurred at considerably higher loads at the same time as the dorsal flexion of the wrist in these experiments was greater than 90°

(4) A greater amount of force was required to produce distal radius fractures in specimens from male individuals compared with female

(5) The results thus clearly suggest that the extent of the injury depends on the amount and direction of the static force



Fig Experimental fracture type I



Fig 8 Experimental fracture type II

Thus although no direct data on the force acting at the moment of fracture can be quoted for this series it seems reasonable to assume that the amount of this force was largely the same as in series II (see below) in which the course of the fracture was recorded and the force of impact ranged from 190 to 440 kp (cf p 24)

In four of the seven experiments in this series the wrist was placed in dorsal flexion varying between 60° and 80° the specimen being arranged so that the pendulum struck the volar surface of the hand In order to determine whether a blow from the opposite direction i e onto the back of the hand produced a different type of fracture the other three experiments were arranged with the wrist in volar flexion between 75° and 80°

In the experiments with the wrist in dorsal flexion and a blow to the palm of the hand the external appearance of the specimen clearly resembled the typical dislocation in which the distal radius fracture bayonets distally On dissection, the fractures in these specimens had the same appearance and tendency to dislocation as those in the static series i e fractures with dorsal dislocation in some cases with a dorsal fragment In the experiments with the wrist in volar flexion and a blow to the back of the hand the specimens displayed deformation of the wrist with volar angulation On dissection fractures were found in all these specimens on the volar face of the distal radius As in the static series these dynamic experiments were conducted with variations in the lateral position of the hand

Discussion The results of these experiments show that clinical types of distal radius fractures can be produced with great regularity under the present conditions for dynamic loading of the specimen The dynamic experiments also indicate more clearly than the static that the wrist injuries produced are closely related to the direction of the force producing the fracture

Dynamic series II

The course of the experiments in this series was recorded with the apparatus described on p 17

The series comprised four experiments three of which resulted in fractures of the distal radius One of these (No 31) was severely comminuted The fourth experiment resulted in multiple injuries in the carpal bones This specimen was subjected to two impact experiments The first fractured the scaphoid capitate and triquetral bones while the second produced further fracturing of these as well as a volar fracture in the lunate bone

Thorough calibration of the impact force gauge in a reversible tension testing machine before each experiment minimized the error of measurement with the apparatus to the levels reported on p 17

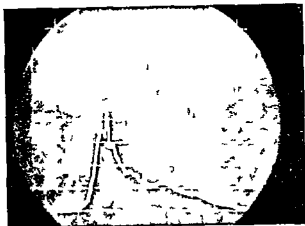


Fig 14

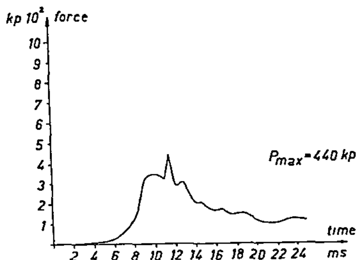


Fig 15

The appearance of the impact curve is illustrated in Figs 14 and 15 which reproduce the original curve as photographed with the Polaroid camera (Fig 14) and the same curve redrawn (Fig 15) The curve in question comes from the experiment on specimen no 32 (cf Table 1) in which the sweep rate of the oscilloscope was 5 ms/ division and the sensitivity 100 kp/division As was the case in the other experiments in this series in which distal radius fractures were obtained the relevant part of the curve spanned 25 ms while its peak occurred after 8–10 ms In this experiment the maximal force when

CHAPTER III

BIOMECHANICAL INVESTIGATIONS

As mentioned in the last chapter, numerous studies have been published concerning the experimental production of fractures in the distal radius Various techniques have been employed As a rule the aim has simply been to reproduce the type of fracture met with in clinical practice without specifically studying the forces required to produce the fracture The results generally show that a particular technique was successful in producing such types of fracture but only in a limited proportion of the series

The incompleteness of earlier series of fracture experiments seems to have been remedied to a considerable extent by the use of special apparatus This has been demonstrated in recent years for experimentally produced fractures of the neck of the femur (C Hirsch & Frankel 1960) of the calcaneum (Thorén 1964) of the knee joint (G Hirsch & Sullivan 1965) and of the ankle joint (C Hirsch & Lewis 1965) The results published by these authors were obtained with two types of biomechanical fracture investigations All except Thorén employed a *static* variant and determined the fracture resulting from a known controllable force (kp) The experiments were made with a hydraulic apparatus (Amsler universal testing machine) to which an automatic writer was attached giving the size of the load in kp Thoren s study on the other hand involved *dynamic* experiments to determine the fracture resulting from varying degrees of external violence (amount of energy) The apparatus used was an Amsler pendulum type impact machine strain gauges fitted to the head of the pendulum and connected to an oscilloscope made it possible to obtain a photographic record of the forces occurring at the moment of fracture

No such biomechanical fracture experiments have been published for the distal radius Consequently it seemed well worth conducting a series of experiments with these two types of apparatus with the aim of reproducing distal fractures of the radius in forearm specimens under static and dynamic loading Such experiments should indicate the amount of the forces producing the fracture and might also indicate suitable conditions for reproducing clinical types of distal radius fractures with greater regularity than has been achieved in previous investigations

The size of a biomechanical experimental series of this type will naturally be limited by the relative scarcity of forearm specimens The uneven supply of such specimens led to the dynamic series of experiments being smaller than the static in the present study This must of course be born in mind when assessing the results

Specimens

The forearm specimens used in the experiments came from autopsies and surgical operations on 23 women and 25 men In the majority (36) of the 48 specimens the forearm had been resected just below the elbow in the other 12 it had been resected about 10 cm above the wrist Two of the women from whom the specimens came were 46 and 56 years old respectively all the others were between 65 and 78 years Most of the men were between 58 and 79 years though five specimens came from men aged 19–50 years None of the above persons had skeletal diseases involving the forearm or hand nor had they any roentgenological signs of osteoporosis

Distal fractures of the radius were produced in 32 of the 48 experiments (Details of these 32 are given in Table 1 at the end of this chapter)

The specimens were either used the same day as they were resected or else stored at −20°C until the day of the experiment when they were thawed at room temperature In both the static and the dynamic experiments the specimen was first freed from soft tissue within a region of about 5 cm from the proximal end after which the fatty tissue in this region was also removed The prepared specimen could then be fixed in a metal holder (C Hirsch 1964) with the aid of a cast compound (Plastic Padding) that hardened at room temperature the forearm being held vertical

Apparatus

Static experiments were conducted with an *Amsler universal testing machine* A kymograph coupled to this machine recorded the size of the load in kp during the course of the experiment together with changes in the distance between the ends of the specimen The testing machine is hydraulically powered and can generate a constant rate of loading In the present experiments this rate was ca 100 kp/min The metal holder into which the specimen had been cast was fixed to the loading head of the machine as indicated in Fig 4 The specimen thus hung vertically the palm resting against a wooden block placed on the machine s supporting head Several different wooden blocks were used in the experiments their upper surface sloping at different angles This made it possible to vary the angle of the wrist as required In the earliest experiments the hand was screwed onto the

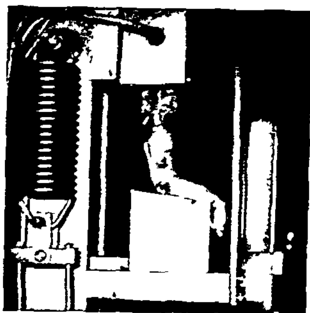


Fig 4. A specimen fixed in the Amsler universal testing machine

block. This technique was abandoned however since the hand of the specimen rested firmly on this type of support without any special fixation

Dynamic experiments were conducted with an *Amsler pendulum type impact machine* the hammer of which was fitted (as described by Thoren 1964) with a tube having a duraluminium plate at one end The metal holder with the specimen was fixed to a large wooden block resting on a steel stand designed in much the same way as that used by Thoren (1964) (Fig 5) The stand was loaded with a given weight resulting in a total weight for the entire apparatus of 75 kg (cf also Fig 6 4 5 6) The loaded stand with the specimen attached rested on a level floor covered with varnished linoleum In view of the conditions being studied nothing was done to eliminate any movement of the stand that might occur during these dynamic experiments The position of the specimen s wrist was varied in a dorsal or volar direction with the aid of a strong nylon string tied between the hand and the stand The specimen and the pendulum were aligned so that on impact, the surface of the pendulum plate lay flat against the surface of the palm or the back of the hand (cf Fig 5)

The dynamic experiments comprised two series The first was only concerned with the apparatus s ability to produce the intended fractures no attempt being made to measure or record the course of the experiment The fracturing force was consequently not determined which naturally detracts from the value of this series However several relevant observations during these experiments seem to justify their inclusion in the following discussion

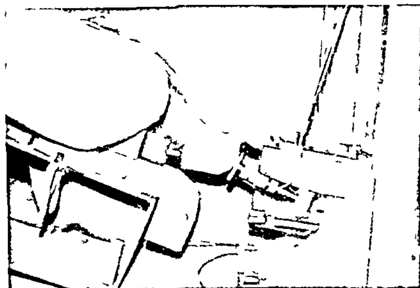


Fig 5 The apparatus used in the dynamic experiments

In the second series of dynamic experiments equipment was included for measuring and recording the force of impact of the pendulum as follows (cf Fig 6) The part of the pendulum (9) carrying the metal plate (8) which delivers the blow to the specimen (5) was designed as a long thin walled tube To this were attached four strain gauges which were coupled via a long screened cable to a balancing unit (3) The out signal of this unit was led to the y axis amplifier of an oscilloscope (2) This apparatus could be calibrated by subjecting the pendulum head (8) to a known load and measuring the deflection on the y axis of the oscilloscope The x axis of the oscilloscope was coupled to a variable time generator The generator could be triggered by a special signal from a triggering unit (1) coupled in its turn to a microswitch (7) The microswitch was placed so that it was actuated a few milli seconds before the impact plate reached the specimen This ensured that the time generator had started when the blow fell besides providing a well defined zero level for the measurements

With this apparatus the curve of the impact force (force in kp versus time in ms) could be read directly from the oscilloscope It could also be recorded with a Polaroid camera attached to the oscilloscope Evaluation of the results was facilitated by introducing a screen through double exposure The apparatus had a total error of measurement of $\pm$ 15 kp at 400 kp max deflection on the y axis and $\pm$ 0 5 ms at 10 ms max deflection on the x axis

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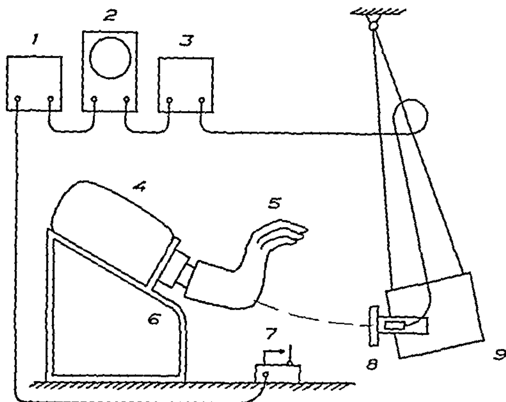


Fig 6 The experimental set up of the second series of dynamic experiments 1 Triggering unit 2 *Oscilloscope* 3 *Balancing unit* 4 Counter weight on specimen stand 5 Specimen 6 Specimen stand 7 Trigger 8 Impact force gauge 9 Pendulum

In both the static and the dynamic experiments x rays were first taken of the wrist of the specimen in two projections This was also done immediately after each experiment The specimen was then dissected and photographs were taken of the exposed fracture

Results of static experiments

A total of 37 static fracture experiments were performed clinical types of distal radius fractures being obtained in 22 The other 15 experiments produced the following injuries fracture of proximal radius ulna (5) proximal radius fracture and distal ulnar dislocation (2) proximal radius fracture (1) distal ulna fracture (1) scaphoid fracture (2) scaphoid and capitate fracture (1) pisiform hamate and capitate fracture (1) triquetral fracture (1) and volar dislocation of the lunate bone with volar fracture in this (1)

The following account is chiefly concerned with the fractures of the distal radius obtained in this series

The 22 experimental fractures of the distal radius classified in the same way as in the follow up series (cf Chapter IV p 30) comprised the following types (I–VIII)

I	II	III	IV	V	VI	VII	VIII
2	1	5	—	1	—	7	6

No less than 19 of them were thus intra articular fractures Six were also accompanied by a fracture somewhere in the caput ulnae usually at the base of the ulnar styloid process (4) *An apparently fresh rupture in the triangular disc in the distal radio ulnar joint* was also found in 5 of the 19 specimens In three of these the rupture was located in the radial part of the disc One specimen with a vertical intra articular fracture in the radio carpal joint also had a ruptured radial collateral ligament

X rays of different types of fracture obtained in these experiments are reproduced in Figs 7—13 The fracture shown in Fig 10 was produced in one of the dynamic experiments

Only fractures with dorsal displacement were obtained in the static experiments probably because only the dorsal flexion and lateral deviation of the wrist were varied *in this series*

The tensile strength of the skeleton did not differ markedly between specimens taken from individuals of different ages but the same sex A clear difference was found on the other hand between the tensile strengths of distal radius in specimens from men compared with women The fracture load for male specimens ranged from 140 to 440 kp (mean 282 kp) while the load for female specimens ranged from 105 to 320 kp (mean 195 kp) see Table 1 It may be noted that under similar experimental conditions no essential difference in tensile strength was found between the short and the long specimens *Nor was there any difference in the types of fracture produced that* could be ascribed to the length of the specimens

Distal fractures of the radius were obtained in the static series when the specimen was loaded with the wrist in 40 –90 dorsal flexion and 0 –35 radial or ulnar deviation In general it seems that the greater the degree of dorsal flexion the larger the force required to produce a fracture

With more than 90 dorsal flexion in the wrist however injuries occurred in the carpal bones (see above) usually involving the scaphoid bone Fracture of the scaphoid alone was *obtained only when the hand* was also in radial deviation multiple injuries to the carpal bones occurred when the hand was midway between radial and ulnar deviation or else in ulnar deviation Injuries to the carpal skeleton also accompanied four of the fractures in the distal radius (only the scaphoid bone in one experiment multiple carpal

injuries in the other three) In these four experiments the course of events followed a particular sequence The fracture in the distal radius seemed to occur first followed by the injury to the carpal bones as the dorsal bending of the specimen increased before the loading could be discontinued. The lateral angulation of the hand in these experiments also resembled the conditions that seemed to apply in other experiments in which carpal injuries occurred without fracture of the distal radius

The loads which led to carpal injuries—from 265 and 510 kp (mean 396 kp)—were considerably higher than those which produced fractures of the distal radius Furthermore the loads which resulted in a combination of distal radius fracture and carpal injuries were generally higher than those which produced a distal radius fracture alone

As already mentioned, eight of the static experiments resulted in proximal fractures in the radius and ulna or only in the radius, in one case combined with distal dislocation of the ulna Although these experiments did not result in the type of fracture aimed at certain features seem worth mentioning here They started in the same way as all the other static experiments—with the specimen resting against a wooden block, the surface of which sloped to varying degrees thereby producing a dorsal flexion of 40–70 in the wrist Loading of the specimen caused the block—and hence the hand—to slide with the result that the angle between the forearm and the hand gradually straightened out When the dorsal flexion in the wrist had dropped to 20–35 the proximal forearm fractures arose at loads between 60 and 190 kp (mean 120 kp) This is considerably less than the loads at which distal radius fractures occurred in the static series

Discussion The results of the static fracture experiments seem to justify the following conclusions

(1) Clinical types of distal radius fractures can be obtained with great regularity on static loading provided the dorsal flexion in the wrist is not less than 40° and not more than 90°

(2) The degree of dorsal flexion in the wrist also seems to be related to the occurrence of fractures in the carpal bones and in the proximal forearm Fractures of the carpal bones occurred when the dorsal flexion in the wrist was more than 90° proximal forearm fractures when it was less than 40°

(3) Considerable force appears to be required to produce a distal fracture of the radius The force required would seem to be related to the degree of dorsal flexion in the wrist since less force produced a fracture when the dorsal flexion was relatively slight Another finding in keeping with this observation is that all the proximal forearm fractures in the series occurred at a lower load than the distal radius fractures at the same time as the dorsal flexion of the wrist in the former was less than 40° Furthermore the carpal bone fractures in this series occurred at considerably higher loads at the same time as the dorsal flexion of the wrist in these experiments was greater than 90°

(4) A greater amount of force was required to produce distal radius fractures in specimens from male individuals compared with female

(5) The results thus clearly suggest that the extent of the injury depends on the amount and direction of the static force




Fig 7 Experimental fracture type I




Fig 8 Experimental fracture type II



Fig 9 Experimental fracture type III

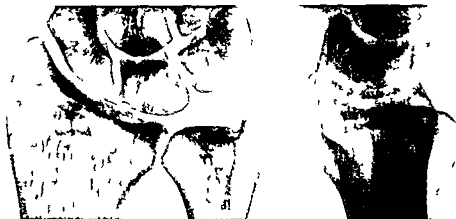


Fig 10 Experimental fracture type IV

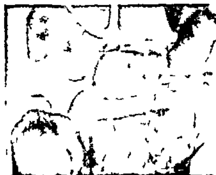




Fig. 11 Experimental fracture type V



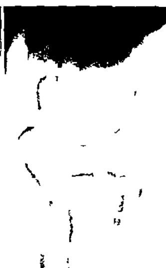


Fig. 12 Experimental fracture type VII

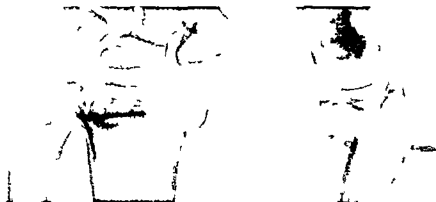


Fig 13 Experimental fracture type VIII

Results of dynamic experiments

The dynamic fracture experiments were performed in two series (see above) The first series comprised seven experiments the second four Only in the second series was the course of events measured and recorded For this reason the results are treated in separate sections below

The 11 dynamic experiments in the two series resulted in clinical types of distal radius fractures in 10 cases One experiment in the second series produced multiple injuries in the carpal bones instead

The ten distal radius fractures were of the following types (I–VIII)

I	II	III	IV	V	VI	VII	VIII
—	1	3	2	—	—	2	2

Nine of them were thus intra articular fractures Half of the radius fractures were accompanied by fractures in the distal ulna in three cases immediately proximal to the caput ulnae As in the static experiments a fresh rupture of the triangular disc was observed after three of the dynamic experiments In two of these specimens the rupture was in the ulnar part of the disc combined with a fracture through the base of the ulnar styloid process In the third the rupture was in the radial part of the disc

Dynamic series I

This was the series in which the course of the experiment was not recorded Consequently no direct data are available for the force producing the fracture The series was undertaken to test the ability of the impact machine to produce distal radius fractures It represents a preparatory study for the second series of dynamic experiments

The Amsler pendulum type impact machine used for these experiments can be pre set by hooking up the pendulum in different positions Given the weight of the pendulum the minimum height of the centre of gravity above the floor and the increment to this height for the different settings of the pendulum it is possible to calculate approximately the kinetic energy of the pendulum at the moment of impact as well as its speed on impact

Prior to this series trials had shown that only the fifth or the sixth setting of the pendulum produced any fractures The calculated kinetic energy and maximal speed on impact for these settings are as follows

Pendulum setting	Kinetic energy		Max speed on impact	
	kpm	kWs	m/s	km/h
5	13 4	131.5	2 66	9 6
6	15 7	153 5	3 12	11 1

Thus although no direct data on the force acting at the moment of fracture can be quoted for this series it seems reasonable to assume that the amount of this force was largely the same as in series II (see below) in which the course of the fracture was recorded and the force of impact ranged from 190 to 440 kp (cf p 24)

In four of the seven experiments in this series the wrist was placed in dorsal flexion varying between 60° and 80° the specimen being arranged so that the pendulum struck the volar surface of the hand In order to determine whether a blow from the opposite direction i e onto the back of the hand produced a different type of fracture the other three experiments were arranged with the wrist in volar flexion between 75° and 80°

In the experiments with the wrist in dorsal flexion and a blow to the palm of the hand the external appearance of the specimen clearly resembled the typical dislocation in which the distal radius fracture bayonets distally On dissection the fractures in these specimens had the same appearance and tendency to dislocation as those in the static series i e fractures with dorsal dislocation in some cases with a dorsal fragment In the experiments with the wrist in volar flexion and a blow to the back of the hand the specimens displayed deformation of the wrist with volar angulation On dissection fractures were found in all these specimens on the volar face of the distal radius As in the static series these dynamic experiments were conducted with variations in the lateral position of the hand

Discussion The results of these experiments show that clinical types of distal radius fractures can be produced with great regularity under the present conditions for dynamic loading of the specimen The dynamic experiments also indicate more clearly than the static that the wrist injuries produced are closely related to the direction of the force producing the fracture

Dynamic series II

The course of the experiments in this series was recorded with the apparatus described on p 17

The series comprised four experiments three of which resulted in fractures of the distal radius One of these (No 31) was severely comminuted The fourth experiment resulted in multiple injuries in the carpal bones This specimen was subjected to two impact experiments The first fractured the scaphoid capitate and triquetral bones while the second produced further fracturing of these as well as a volar fracture in the lunate bone

Thorough calibration of the impact force gauge in a reversible tension testing machine before each experiment minimized the error of measurement with the apparatus to the levels reported on p 17



Fig 14

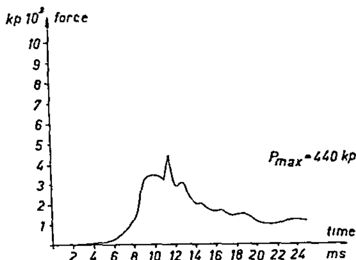


Fig 15

The appearance of the *impact curve is illustrated in* Figs 14 and 15 which reproduce the original curve as photographed with the Polaroid camera (Fig 14) and the same curve redrawn (Fig 15) The curve in question comes from the experiment on specimen no 32 (cf Table 1) in which the sweep rate of the oscilloscope was 5 ms/ division and the sensitivity 100 kp/division As *was the case in the other experiments in this series in which distal radius* fractures were obtained the relevant part of the curve spanned 25 ms while its peak occurred after 8–10 ms In this experiment the maximal force when

the specimen fractured was calculated to 440 kp In the other two experiments that resulted in distal radius fractures, the maximal force was calculated to 350 and 190 kp respectively

The two highest values relate to specimens from men the lowest to a specimen from a woman

In the experiment which resulted in multiple injuries to the carpal bones the maximal force of the first impact was calculated to 440 kp that of the second to 680 kp

It should be noted that the maximal load of 350 kp was achieved with the impact pendulum in setting no 5 while the other experiments were conducted with the pendulum starting from setting no 6

The dorsal flexion in the wrist was varied very little between these four dynamic experiments Two of the specimens were arranged with the hand in slight radial deviation the other two with the hand in slight ulnar deviation In view of the small differences in the position of the wrist as well as the small number of specimens in this series no conclusions can be drawn about the relationship between the amount of the force and the position of the wrist during the experiment

All three fractures of the distal radius were of the dorsal dislocation type no doubt because all these experiments were performed with the wrist in dorsal flexion and the impact striking the volar surface of the hand

Discussion This second series of dynamic experiments also produced clinical types of distal radius fractures with satisfactory regularity The position of the wrist in these experiments corresponded to the conditions in the series discussed above Once again the direction of the force of impact determined the direction of displacement in the fracture The amount of the force measured at the moment of impact was very considerable in this series as it was in the static experiments though the values were inside the limits obtained in the static series

Summary of results from the biomechanical experiments

It is clear that both static and dynamic force can produce clinical types of distal radius fractures with great regularity provided the wrist of the specimen is positioned in a certain angle The direction of the blow then appears to determine the direction of the resultant fracture s displacement Thus in the static experiments—in which only the dorsal flexion and lateral deviation of the wrist were varied—all the fractures displayed dorsal displacement It was shown in some of the dynamic experiments that when instead a hand in volar flexion was loaded from the dorsal side, volar fractures were produced with volar displacement

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TABLE I *Factors of interest by the production of the fractures of the distal radius*

Specimen No	Sex	Age	Position of the hand in degrees: Dorsal flexion	Volar flexion	Radial deviation	Ulnar deviation	Resultant fracture: Dorsal	Volar	Type of fracture	Maximum force (kp)	Simultaneous carpal bone fracture	Lesion of the triangular disc
Static type of experiment												
1	F	56	80				+		VIII	240	+	–
2	M	59	70				+		VII	440	–	–
3	F	67	45			15	+		III	260	–	–
4	F	78	65		10		+		III	145	–	+
5	F	65	60		20		+		VII	180	–	+
6	F	65	65		15		+		V	105	–	–
7	F	78	55			20	+		III	150	–	–
8	F	78	45		30		+		VIII	130	–	+
9	F	67	65			15	+		VIII	130	–	+
10	F	67	60			20	+		VII	320	–	–
11	M	72	65		10		+		VII	440	+ (620 kp)	–
12	M	68	90		20		+		III	440	+ (630 kp)	–
13	M	66	75		15		+		VII	300	–	–
14	M	66	85			5	+		I	170	–	–
15	F	78	60		15		+		III	250	+	–
16	M	72	75			10	+		VII	170	–	–
17	M	19	80				+		II	170	–	–
18	F	78	90		20		+		VIII	220	–	–
19	F	46	40			30	+		VII	160	–	–
20	M	50	90			10	+		VIII	270	+	–
21	F	72	80		35		+		VIII	250	–	+
22	M	61	80				+		I	140	–	–
Dynamic type of experiment												
23	F	78	100				+		III	?	–	–
24	F	78		75				+	III	?	–	–
25	M	61	60			15	+		VII	?	–	–
26	M	61	80		15		+		VIII	?	–	–
27	F	68		85		10		+	III	?	–	–
28	F	68		80		15		+	VIII	?	–	–
29	F	65	80			10	+		IV	?	–	+
30	M	58	80		15		+		VII	350	–	–
31	F	69	70			10	+		II	190	–	+
32	M	31	60		10		+		IV	440	–	+

CHAPTER IV

TYPES OF FRACTURE

Considerable interest and effort have been expended on the systematic classification of these fractures The use of different clinical factors as a basis for these systems has unfortunately resulted in the publication of such a wide variety of classifications that some authors (e g Chandler 1950) have *warned of the dangers of confusion Most authors (e g* Kotrnetz & Geiringer 1937 Arbeitlang & Boeckl 1963 van Trappen 1964) point to the value of arranging fractures of the distal radius in separate groups because different types present different problems of treatment and may even have a different prognosis Similarly Wiklund & Mullern Aspegren (1956) hold that one cannot compare the results of different methods of treatment unless one first defines the different types of fracture

As Lidstrom (1959) points out most of the numerous systems for classifying fractures of the distal radius appear to have been used in practice only by their authors (Kahleyss 1897 Hitzrot & Murray 1921 Ghormley & Mroz 1932 Cornell 1935 Ehalt 1935 Kotrnetz & Geiringer 1937) One reason for this is probably the extremely detailed nature of these classifications particularly that published by Ehalt (1935) with no less than thirty four different *groups for such fractures in adults Only four published classifications have* been at all widely accepted namely those by Destot (1923) Taylor & Parsons (1938) Nissen Lie (1939) and Gartland & Werley (1951) Before commenting on these here is a brief review of the various primary factors upon which published classifications have been based

The *site of the fracture in relation to the wrist joint* is usually noted by distinguishing between extra and intra articular fractures of the distal radius In general no notice is taken of whether an intra articular fracture involves only the radio carpal or only the distal radio ulnar joint or both On the other hand attention is often paid to the *degree of joint involvement* as a result of any comminution of the distal fragment Some authors have even distinguished between *T* and *Y* shaped fractures *involving comminution* with a *further* category for fractures causing disruption of an ulnar fragment

The *direction of displacement* has also been used both separately and more commonly in combination with the factors mentioned above for classifying fractures of the distal radius Practically all the known forms of displacement

of the distal radius fragment have been noted—with or without compression or widening—and serve as distinguishing characteristics in several classifications particularly those of Pilcher (1917) Humphries (1948) Key (1954) and Arbeitlang & Boeckl (1963) In general, however, complicated divisions on this basis have been avoided by considering only two groups those with dorsal and those with volar displacement The *degree of displacement* is also frequently used as a basis for classification fissure fractures and fractures without displacement commonly forming a single group while the dislocated fractures are usually subdivided according to the degree of displacement

Some authors regard *injury to the distal radio ulnar joint* as such an important factor in the clinical picture that they base their systems upon its presence or absence

Some systems have been based on the *mechanism of injury* the distinction being between avulsion fractures and those occasioned by a blow and counter blow In this context the position of the hand at the moment of injury has given rise to different groups for extension flexion abduction and adduction fractures for which different fracture lines have been observed (Cornell 1935)

As already mentioned only four systems of classification based on some of these factors have won any general acceptance These will now be considered separately

Destot (1923) used the direction of displacement as his basic principle distinguishing between anterior and posterior fractures The former are subdivided into fractures of the radial styloid process fractures of the volar margin and Smith s fracture while the latter comprise Colles fracture and fracture of the dorsal margin (Barton s fracture) This system has also been employed by Platt (1931) and Hoffman (1953)

Taylor & Parsons (1938) also had only two main groups based upon the presence or absence of disc injury in the distal radio ulnar joint Only the group with disc injury is subdivided partly according to whether or not the distal radius has a comminuted fracture Mayer (1940) and Manges Jr (1941) have subsequently adopted this system

Nissen Lie (1939) took several factors into account in his classification including the site of the fracture in relation to the joint surface the degree of joint involvement the direction and the degree of displacement Fractures in adults were thus divided into five groups 1 Fissure fractures with little or no displacement 2 Extra articular fractures with dorsal and radial displacement 3 Comminuted fractures with one or several fracture lines involving the joint and considerable displacement of the fragment 4 Fractures of the radial styloid process 5 Fractures with volar displacement Several authors in Scandinavia have adopted Nissen Lie s system e g Rosen (1947) E Madsen (1949) Wiklund & Mullern Aspegren (1956) and Djorup (1962)

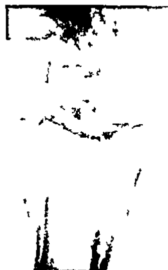



Fig 16 Fracture type I




Fig 1 Fracture type II



Fig 18 Fracture type III



Fig 19 Fracture type IV



Fig 20 Fracture type V



Fig 21 Fracture type VI

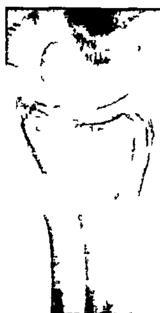



Fig ‿2 Fracture type VII




Fig ‿3 Fracture type VIII

Gartland & Werley (1951) finally distinguished between three groups according to the fracture's position in relation to the radial articular surface the degree of joint involvement and the degree of displacement 1 Simple Colles fracture not involving the radial joint surface 2 Comminuted Colles fracture involving the joint surface but without displacement in this 3 Comminuted Colles fracture involving the joint surface and with displacement of the fragments Those who have subsequently followed this division include de Palma (1952) and K. P Madsen (1959)

Lidström (1959) adopted the principle that only the factors which tend to elucidate certain clinical problems should be included *in a system of classification* His system largely followed that drawn up by Kotrnetz & Geiringer (1937) which took into account the degree and direction of displacement joint involvement and the degree of comminution By modifying this system Lidström rendered it simpler and probably enhanced its clinical value The resultant arrangement comprised three main groups I Fissure fractures and fractures with no appreciable displacement II Fractures with posterior displacement III Fractures with volar displacement The fractures in group I were held not to pose any clinical problems excellent results being generally *obtained irrespective of the treatment A distinction was made between the* fractures of groups II and III because the mechanism behind them differs and consequently they require different techniques of reduction In view of the factors mentioned above fractures with posterior displacement had to be subdivided and Lidstrom's complete classification appeared as follows

I Fissure fractures and fractures with no appreciable displacement

II Fractures with posterior displacement
- A Fractures with merely dorsal angulation not involving the joint surface
- B Fractures with merely dorsal angulation involving the joint but without comminution of the articular surface
- C Fractures with complete displacement not involving the joint surface
- D Fractures with complete displacement involving the joint but without comminution of the articular surface
- E Fractures with complete *displacement and comminution of the joint* surface

III Fractures with volar displacement

Commenting on this system Lidström notes that fractures of the radial styloid process with displacement are included in group II E while other fractures with displacement belong to groups II C II D or II E depending on the degree of joint involvement Further group II corresponds to Nissen Lie's groups 2 and 3 (simple fracture dislocations without *joint involvement*

and comminuted fractures) the two types of fracture most often discussed in the Scandinavian literature

Classification used in the present study

In the present study in keeping with the principles adopted at the Department of Bone and Joint Surgery at Sahlgrenska Sjukhuset, it was not considered that the primary displacement should constitute an important factor in the system of classification This is because the degree of primary displacement as measured on roentgenograms is hardly even an approximate indication of the actual displacement at the time of the fracture It therefore seems worthless as a criterion Nor judging from the literature does it seem that the direction of displacement is sufficiently important to necessitate consideration in this context For the same reason, the degree of comminution in the distal fragment of the radius has been deemed irrelevant in a classification system this factor impairs the prognosis only if the fracture reaches and causes displacement in the articular surfaces on the radius Since instead it is presumably valuable—both for the prognosis and to some extent for treatment—primarily to determine the extent of involvement of the fracture in both the radiocarpal and the distal radio ulnar joint this has been adopted as the guiding principle for the classification of fractures in the present series This principle largely corresponds to that published by Gartland & Werley (1951) i e the system subsequently accepted by e g de Palma (1952) and K P Madsen (1959)

The basic distinction in this system is between extra and intra articular fractures of the distal radius In addition consideration is paid to whether or not there is also a fracture of the distal ulna the reason for this being the deleterious effect which such fractures have on the prognosis for the fractures of the distal radius in this series The complete system of classification used here is as follows

I Extra articular fractures without fracture of the distal ulna (Fig 16)
II Extra articular fractures accompanied by fracture of the distal ulna (Fig 17)
III Intra articular fractures involving the radio carpal joint but without fracture of the distal ulna (Fig 18)
IV Intra articular fractures involving the radio carpal joint and accompanied by fracture of the distal ulna (Fig 19)
V Intra articular fractures involving the distal radio ulnar joint but without fracture of the distal ulna (Fig 20)
VI Intra articular fractures involving the distal radio ulnar joint and accompanied by fracture of the distal ulna (Fig 21)

VII Intra articular fractures involving both the radio carpal and the distal radio ulnar joint but without fracture of the distal ulna (Fig 22)

VIII Intra articular fractures involving both the radio carpal and the distal radio ulnar joint and accompanied by fracture in the distal ulna (Fig 23)

Discussion

This classification has been applied consistently throughout the series regardless of whether the case involved a fissure fracture fracture with only slight displacement or fracture with considerable displacement Nor as already mentioned has primary consideration been paid to the direction of displacement (as for instance in Lidstrom s (1959) series in which a distinction was made between fractures with dorsal and volar displacement) Although no conclusive reasons for making such a distinction could be found in the literature a separate study has however been made of the functional end results for fractures with volar displacement in order to assess any difference that may exist in the results for fractures with this type of displacement Similar special studies have also been made of the results for fissure fractures fractures with *only slight displacement and fractures with more pronounced* displacement (fissure fractures, unreduced fractures and reduced fractures) Any significance discovered for these factors will be discussed in a subsequent chapter

the follow up examination and consequently it has been omitted Accordingly, *the calculations presented below refer to the remaining 430 cases in the follow up series*

The sex distribution in the follow up series agrees fairly well with that for the complete series and for other series published earlier (see above) The proportions are thus 80 9% women and 19 1% men compared with 78 1 and 21 9% in the complete series and 81 1 and 18 9% in Lidström s

While the age distribution in the follow up series is also much the same as in the complete series (see Table 3) there are some exceptions Both the youngest and in particular the oldest age groups have become smaller The reduction in the youngest groups is chiefly due to unwillingness to take part in the examination but partly because the patients had left Gothenburg and could not be traced The smaller size of the older age groups is due to all the deaths having occurred here as well as to the patients unwillingness to participate for reasons of age The maximum incidence among the women is still between 56 and 65 years Among the men it is in the lower age groups though both 36–45 years and 46–55 years now have a high incidence There is still a high incidence of men in the lowest age group No definite explanation could be found for this circumstance A possible factor may be the inclusion of radius fractures without displacement (i e without reduction) in the series While the predominace of men in the youngest age groups applies to both the reduced and the un reduced cases it is most marked in the latter (cf Tables 4 and 5)

The 430 cases in the follow up series are arranged by type of fracture sex and age groups in Table 6 There is a remarkable predominance of intra articular fractures which account for about two thirds of the series This is most unlike the pattern usually reported in the literature, where the extra articular fractures account for two thirds or more of published series (Nissen Lie 1939 Lidstrom 1959 van Trappen 1964) This discrepancy cannot be explained by the inclusion of both reduced and un reduced fractures since as shown

TABLE 3 *Distribution by age and sex (follow up series)*

	Age								
	16–25	26–35	36–45	46–55	56–65	66–75	76–85	86–95	Total
Men	15	8	17	18	16	8	—	—	82 19 1%
Women	8	13	22	67	126	97	14	1	348 80 9%
Total	23 5 3%	21 4 9%	39 9 1%	85 19 8%	142 33 0%	105 24 4%	14 3 3%	1 0 2%	430

TABLE 4 *Distribution of age groups by type of fracture and sex (?9o reduced cases)*

Age	Type of fracture I ♀	I ♂	II ♀	II ♂	III ♀	III ♂	IV ♀	IV ♂	V ♀	V ♂	VI ♀	VI ♂	VII ♀	VII ♂	VIII ♀	VIII ♂	Total ♀	Total ♂	Total
16–25	—	1	3	2	—	—	—	1	—	1	3	1	—	1	—	2	6 2 0%	9 3 1%	15 5 1%
26–35	—	—	4	—	1	1	1	1	2	—	2	—	—	—	1	—	11 3 7%	2 0 7 %	13 4 4 %
36–45	—	1	3	1	1	2	1	3	1	—	6	1	—	1	1	1	13 4 4 %	10 3 4 %	23 7 8%
46–55	1	—	11	1	1	5	5	3	3	1	14	4	2	—	10	1	47 15 9%	15 5 1%	62 21 0 %
56–65	9	—	12	2	5	—	11	1	7	2	18	—	6	—	17	2	85 28 8%	7 2 4%	92 31 2%
66–75	13	—	15	—	1	—	12	—	2	—	11	—	2	—	15	1	75 25 4%	1 0 3 %	76 25 7%
76–85	4	—	4	—	2	—	—	—	—	—	2	—	—	—	1	—	13 4 4%	— —	13 4 4%
86–95	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1 0 3%	—	1 0 3%
Total	27	2	52	6	11	8	30	9	15	4	7	6	10	2	19	7	251 85 0	44 15 0%	295
	29 9 8%		58 19 7%		19 6 4%		39 13 2%		19 6 4 %		13 4 4%		12 4 1%		26 11 0%		295		

TABLE 5 *Distribution of age groups by type of fracture and sex (135 un reduced cases)*

Age	Type of fracture I ♀	I ♂	II ♀	II ♂	III ♀	III ♂	IV ♀	IV ♂	V ♀	V ♂	VI ♀	VI ♂	VII ♀	VII ♂	VIII ♀	VIII ♂	Total ♀	Total ♂	Total
10–25	—	3	1	1	—	1	1	—	—	1	—	—	—	—	—	—	2	6	8
																	1 5%	4 4%	5 9%
20–35	2	2	—	—	—	2	—	—	—	2	—	—	—	—	—	—	2	6	8
																	1 5%	4 4%	5 9%
30–45	5	2	2	1	1	3	—	1	1	—	—	—	—	—	—	—	9	7	16
																	6 7%	5 2%	11 9%
40–55	7	1	3	—	3	1	2	—	1	—	2	—	1	—	1	1	20	3	23
																	14 8%	2 2%	17 0%
50–65	15	3	6	2	8	2	4	1	3	—	3	1	—	—	1	—	40	9	49
																	29 6%	6 7%	36 3%
60–75	6	1	4	1	3	1	5	1	3	1	1	1	—	1	1	—	23	7	30
																	17 0%	5 2%	22 2%
70–85	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
																	0 7%	—	0 7%
80–95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
																	—	—	—
Total	36	12	16	5	15	10	12	3	8	4	6	2	1	1	3	1	97	38	135
																	71 9%	28 1%	
	48		21		25		15		12		8		2		4		135		
	35 6%		15 5%		18 5%		11 1%		8 9%		5 9%		1 5%		3 0%				

TABLE 6 *Distribution of age groups by type of fracture and sex in follow up series*

Age	Type of fracture I ♀	I ♂	II ♀	II ♂	III ♀	III ♂	IV ♀	IV ♂	V ♀	V ♂	VI ♀	VI ♂	VII ♀	VII ♂	VIII ♀	VIII ♂	Total ♀	Total ♂	Total
16–25	—	4	4	3	—	1	1	1	—	2	3	1	—	1	—	2	8 1 9%	15 3 4%	23 5 3%
26–35	2	2	4	—	1	3	1	1	2	2	2	—	—	—	1	—	13 3 0%	8 1 9%	21 4 9%
36–45	5	3	5	2	2	5	1	4	2	—	6	1	—	1	1	1	22 5 1%	17 4 0%	39 9 1%
46–55	8	1	14	1	4	6	7	3	4	1	16	4	3	—	11	2	67 15 6%	18 4 2%	85 19 8%
56–65	25	3	18	4	13	2	1[illegible]	2	10	2	21	1	6	—	18	2	1[illegible]6 29 3%	16 3 7%	142 33 0%
66–75	18	1	19	1	4	1	17	1	5	1	12	1	2	1	20	1	97 22 5%	8 1 9%	105 24 4%
76–85	5	—	1	—	2	—	—	—	—	—	2	—	—	—	1	—	14 3 3%	— —	14 3 3%
86–95	—	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	1 0 2%	— —	1 0 2%
Total	63 14 6%	14 3 3%	68 15 8%	11 2 6%	[illegible]6 6 0%	18 4 [illegible]%	42 9 7%	12 [illegible]8%	23 5 3%	8 1 9%	63 14 6%	9 1 9%	11 2 6%	3 0 7%	5[illegible] 12 1%	8 1 9%	348 80 9%	82 19 1%	430
	77 17 9%		[illegible]9 18 1%		44 10 [illegible]		54 1[illegible] 5[illegible]		31 7 2		71 16 [illegible]%		14 3 3%		60 14 0%		430		

by Tables 4 and 5 the intra articular fractures do not predominate among the cases not subjected to reduction Instead I should like to put forward a different explanation

In reports on these fractures in the literature it is usual to record the presence of joint involvement in the distal radius This is generally taken to mean just the fracture s involvement of the distal articular surface of the radius and it is only exceptionally that mention is made of the ulnar articular surface in this context (Fagge 1929, Lang 1942 Chandler 1950) Although many authors have studied injuries to the soft tissues in the distal radio ulnar joint in connection with distal fractures of the radius *no one appears to have drawn attention to this fracture s solitary involvement of the distal radio ulnar joint* in my opinion a common and clinically important variant of this fracture I suspect that a large proportion of the fractures described in the literature as extra articular and affecting the distal end of the radius were in fact intra articular in the distal radio ulnar joint This opinion is supported by the following simple calculation if the 102 fractures in the present series with intra articular involvement of only the distal radio ulnar joint are transferred to the group of extra articular fractures the latter will comprise 60% of the series i e much the same incidence as that usually reported for extraarticular fractures in the literature

The age distribution shown in Table 6 also largely corresponds to that generally reported in the literature The present study gave no indication that the distribution by type of fracture is influenced by the age factor

There are 19 fissure fractures among the 430 cases in the follow up series and their distribution by age sex and type of fracture is shown in Table 7 It may be noted that the number of intra articular fractures in this group amounts to considerably less than 50% in contrast to the proportion in the rest of the follow up series There are more fissure cases in the youngest age groups and they are relatively more common among the men

The follow up series also includes 17 cases with volar displacement in the radius fracture Their distribution by age sex and type of fracture is given in Table 8 In relation to the total follow up series there is a higher proportion of men in this group which is also somewhat over represented in the youngest age groups

Both the fissure fractures and the volar fractures will be discussed separately in a subsequent chapter

Discussion

Out of the complete series of 516 cases between 16 and 95 years of age follow up examination was originally performed on 431 or 83 5% This is a

TABLE 7 Distribution of fissure fractures by type of fracture sex and age

Age	Type of fracture I ♀	♂	II ♀	♂	III ♀	♂	IV ♀	♂	V ♀	♂	VI ♀	♂	VII ♀	♂	VIII ♀	♂	Total ♀	♂	Total
16–25	—	2	—	1	—	1	—	—	—	—	—	—	—	—	—	—	—	4	4
26–35	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	[illegible]	—	2
36–45	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
46–55	1	—	—	—	[illegible]	—	—	—	—	—	—	—	—	—	—	—	3	—	3
56–65	3	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	1	4
66–75	—	—	—	—	2	—	1	—	1	—	—		—	—	—	—	4	—	4
76–85	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	1
86–95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	8	3	—	1	4	1	1	—	1	—	—	—	—	—	—	—	14 73 7%	5 26 3%	19
	11		1		5		1		1		—		—		—		19		

TABLE 8 *Distribution of fractures with volar displacement by type of fracture sex and age*

Age	Type of fracture: I ♀	I ♂	II ♀	II ♂	III ♀	III ♂	IV ♀	IV ♂	V ♀	V ♂	VI ♀	VI ♂	VII ♀	VII ♂	VIII ♀	VIII ♂	Total ♀	Total ♂	Total
16–25	—	1	—	—	—	—	—	1	—	—	—	—	—	1	—	—	—	3	3
26–35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
36–45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
46–55	—	—	1	—	—	2	1	2	—	—	—	—	—	—	—	—	2	4	6
56–65	—	—	1	—	—	—	2	—	—	—	—	—	1	—	1	—	5	—	5
66–75	—	—	2	—	—	—	—	—	—	—	—	—	—	—	1	—	3	—	3
76–85	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
86–95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—			
Total	—	1	4	—	—	2	3	3	—	—	—	—	1	1	2	—	10 59%	7 41%	17
	1		4		2		6		—		—		2		2		17		

relatively high figure compared with for instance *Lidström's* (1959) series with 68% Lidström was unable to determine whether his 68% were representative of the total series but he did find good agreement in the distribution by age and type of fracture between those who were examined and those who were not He therefore concluded that since the treatment had been uniform there was good reason to suppose that the follow up series was in fact representative of the total series Moreover a questionnaire was sent to some of the unexamined patients asking about their recovery 58% of these replied that they were completely free from discomfort In the follow up series the same subjective opinion had been given by 54%

Turning to the distribution by age sex and type of fracture for the unexamined cases in the present series (Table 9) it will be seen that the youngest and oldest age groups account for a larger proportion than they do with respect to the follow up series (Table 6) This is explained both by the difficulty of interesting the youngest individuals in a follow up examination, since they considered themselves entirely recovered and by the fact that all the deaths occurred in the highest age groups On a sex basis most of the unexamined cases among the women were in high age groups while most of those among the men were in low age groups Deaths and a reluctance induced by age explain the drop out among the women while many of the young men were unwilling to participate because they considered themselves recovered Concerning the distribution of those not included in the follow up by type of fracture somewhat more had extra articular injury than in the follow up group Moreover the intra articular fractures have fewer complicated cases in the group not included in the follow up than in the follow up series This agrees to some extent with the findings reported by Lidstrom (1959) It could possibly be explained by the fact that the incidence of severe fractures is lower in the younger age groups than in the older an effect which would be heightened by the over representation of individuals in the younger groups

A skewness of this sort in the series not included in the follow up may of course detract from the value of the results of this series and make it less representative of the complete series The discrepancies however chiefly favour the younger age groups and the simpler types of fracture both of which are known to be favourable prognostic factors Thus an increased participation by the patients not included in the follow up could be expected to produce a generally better functional end result

Only in the case of minor differences therefore will discrepancies in the composition of the total series and the follow up series introduce an element of uncertainty In other respects the follow up series must be regarded as representative (*cf* also the distribution of the total and the follow up series by type of fracture and age groups in Tables 10 and 6)

TABLE 9 *Distribution of cases not followed up by type of fracture sex and age*

Age	Type of fracture																Total		
	I		II		III		IV		V		VI		VII		VIII				
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	Total
10–25	1	1	—	2	1	2	—	2	—	—	—	—	—	—	—	—	2 2 4%	7 8 2%	9 10 6%
20–35	—	4	2	1	1	—	—	2	—	—	—	—	—	1	—	1	3 3 5%	9 10 6%	12 14 1%
30–45	–	—	1	—	—	1	—	2	—	—	—	—	—	—	—	1	1 1 2%	4 4 7%	5 5 9%
40–55	2	—	2	—	1	2	1	1	—	—	1	—	—	—	1	—	8 9 4%	3 3 5%	11 12 9%
50–65	2	—	2	—	—	2	—	1	—	—	3	—	—	—	2	—	9 10 6%	3 3 5%	12 14 1%
60–75	3	—	3	1	—	1	3	—	3	—	2	1	—	—	—	—	14 16 5%	3 3 5%	17 20 0%
70–85	3	—	6	—	—	—	—	1	—	—	3	—	—	—	—	—	12 14 1%	1 1 2%	13 15 3%
80–95	—	—	1	—	—	—	3	—	—	—	—	—	—	—	2	—	6 7 1%	— —	6 7 1%
Total	11	5	17	4	3	8	7	9	3	—	9	1	—	1	5	2	55 64 7%	30 35 3%	85
	16 18 8%		21 24 7%		11 12 9%		16 18 8%		3 3 5%		10 11 8%		1 1 2%		7 8 2%		85		

TABLE 10 *Distribution of age groups by type of fracture and sex in total series*

Age	I ♀	I ♂	II ♀	II ♂	III ♀	III ♂	IV ♀	IV ♂	V ♀	V ♂	VI ♀	VI ♂	VII ♀	VII ♂	VIII ♀	VIII ♂	Total ♀	Total ♂	Total
16–25	1	5	4	5	1	3	1	3	—	2	3	1	—	1	—	2	10 1 9%	22 4 3%	32 6 2%
26–35	2	6	6	1	2	3	1	3	2	2	2	—	—	1	1	1	16 3 1%	17 3 3%	33 6 4 %
36–45	5	3	6	2	2	6	1	6	2	—	6	1	—	1	1	3	3 4 5 %	22 4 2%	45 8 7%
46–55	10	1	16	1	5	8	8	4	4	1	17	4	3	—	12	2	75 14 5%	21 4 1%	96 18 6%
56–65	27	3	20	4	13	4	15	3	10	2	24	1	0	—	20	2	135 20 2 %	19 3 7%	154 29 9 %
66–75	21	1	22	2	4	2	20	1	8	1	14	2	2	1	20	1	111 21 5%	11 2 1 %	122 23 6%
76–85	8	—	10	—	2	—	—	1	—	—	5	—	—	—	1	—	26 r 0%	1 0 2%	27 5 %
86 95	—	—	1	—	—	—	3	—	—	—	1	—	—	—	2	—	7 1 4%	— —	7 1 4%
Total	74 14 3%	19 3 7%	85 16 5%	15 2 9%	29 5 6%	26 5 0%	40 0 5%	21 4 1 %	26 5 0%	8 1 6%	72 14 0%	9 1 7 %	11 2 1%	4 0 8%	57 11 1%	11 2 1%	403 78 1%	113 21 9 %	516
	93 18 0%		100 19 4%		55 10 6%		0 13 6%		34 6 6%		81 15 7%		15 2 9%		68 13 2%		516		

CHAPTER VI

GENERAL ASPECTS OF TREATMENT, WITH SPECIAL REFERENCE TO THE PRESENT SERIES

Considerable space has been devoted to the subject of treatment in many previous reports on the clinical aspects of distal radius fractures The account which I have found most complete in this respect is that published by Lidstrom (1959) in which the problem is approached from the following angles (1) Technique of reduction, (2) Appropriate time for reduction (3) Method of anaesthesia, (4) Technique of immobilization (5) Duration of immobilization (6) Position of the hand during immobilization, and (7) Physical therapy In view of the completeness of this account I feel it would be unnecessarily repetitive to present a further review of the relevant literature here Instead the reader is referred to Lidström s monograph for reference to literature up to 1959 The following account based on the headings listed above is a brief review of more recent publications in this field coupled with the related information arising out of the present follow up investigation

Technique of reduction

The reduction technique described by Bohler (1923) still seems to be most widely used (Lidstrom 1959 Hamsa 1962, Guttman 1964 Older, Stabler & Cassebaum 1965 Soren 1965) though some authors still refer to the technique described by Robert Jones (1915) which now appears to be practised largely in Anglo Saxon countries (Sponsel 1964) Kane (1964) however has emphasised the importance of allowing for the primary displacement in the individual fracture when reducing this

Authors continue to point out that Bohler's technique requires rather a large staff and attempts have been made to apply new forms of extension apparatus instead of manual traction during reduction (Grath, 1956) or else the use of finger traction with the help of Chinese finger stalls (Older Stabler & Cassebaum 1965) The extension apparatus described by Grath (used in several cases in the present series) can be employed for fractures of the distal radius as well as for forearm fractures while a slight modification makes it suitable for fractures of the lower leg as well The apparatus is easy to apply on an ordinary operating table and the extension is achieved by traction on

all the fingers but not the thumb the former being fixed midway up the proximal phalanges by an adjustable rubberized cuff A system of springs makes it possible to adjust the traction to the desired number of kilograms

Own cases There were 295 cases among the 430 in the present follow up series in which the primary treatment involved *closed reduction* Bohler s technique had been used in all these cases though in 31 of them manual traction had been replaced by traction with the extension apparatus described by Grith (1956) The dorsal or volar displacement had been corrected by volar or dorsal flexion of the hand as well as by direct pressure against the distal fragment Secondary *open reduction* had been performed in 7 cases at various intervals after the primary reduction in order to correct a persistent displacement the fracture being fixated either with a loop of steel wire passed through the bone or with a Kirschner wire implanted subcutaneously

Appropriate time for reduction

Little of importance has been contributed to this topic since Lidstrom s monograph (1959) Immediate reduction is still generally considered preferable to any delay (Guttman 1959 K P Madsen 1959) though Golden (1963) is of the opinion previously put forward by e g Kotrnetz & Geiringer (1937) that the reduction should not be carried out until at least 24 hours after the accident This is believed to reduce the risk of renewed haemorrhage in the fracture region thereby diminishing the post traumatic swelling and the number of early circulatory disturbances An intermediate position has been adopted by Sponsel (1965) who prefers to delay reduction except in cases of open fracture or pronounced dorsal dislocation

Own cases Reduction was performed only a few hours after the injury in the great majority of the 295 cases given this treatment in the present series The result was checked by X ray examination and a renewed attempt was made if the previous one proved unsatisfactory

There were 29 cases in which the reduction had not been performed immediately because the patients waited before applying for treatment In 15 of these cases however no more than 12–24 hours elapsed between the accident and the time of reduction More than 24 hours (in one case as much as a week) elapsed before reduction in the remaining 14 cases Even so the post reduction course in these cases did not differ significantly from that in the cases in which reduction could be performed without delay

The 7 cases in which open reduction was performed as a secondary measure constitute a special group among the reduced cases Primary closed reduction had been attempted in all these cases but had either failed or soon been followed by re dislocation in the fracture whereupon it was decided that surgical

treatment was indicated In these cases the open reduction was undertaken between 1 and 7 days after the accident

As already indicated the follow up series includes 135 cases in which reduction was not performed The two types of extra articular fractures accounted for 69 of these while 40 of the remaining 66 were intra articular only in the radio carpal joint 20 occurring only in the distal radio ulnar joint and 6 in both these joints The dorsal angulation amounted to less than 10° in 83 of these 135 cases to between 10 and 20 in 50 cases and to between 20 and 30 in 2 cases One of the last two cases was a re fracture and since it was considered that part of the displacement was probably residual from the first fracture reduction was not attempted after the present injury In the other case reduction was not performed on account of the patient s advanced age

Method of anaesthesia

Judging from publications on fractures of the distal radius in recent years complete agreement still seems to be lacking as to which form of anaesthesia is most suitable for obtaining the best results from reduction Local anaesthesia still seems to be the method most generally used (Schwetlick 1962 Sponsel 1964 Sorén, 1965) while some authors recommend general anaesthesia only (e g Miller 1960) and others are not so categorical Thus Mack (1959) and Gambier & Venturini (1964) recommend local anaesthesia for elderly patients and general anaesthesia or brachial block for younger while van Trappen (1964) and Older Stabler & Cassebaum (1965) recommend local anaesthesia for simple types of fracture and general anaesthesia or brachial block for more complicated

In Lidström s (1959) series local anaesthesia had been used at reduction in 388 out of 486 cases Lidström points out that more than a quarter of these patients stated at the follow up examination that they would have preferred a general anaesthesia on account of the severe pains which they experienced during the manipulations for reduction There were 98 patients in Lidström s series who received a general anaesthesia reduction having first been attempted under a local anaesthesia in 14 In a further 6 cases in which an initial attempt at reduction under local anaesthesia had failed a brachial block was used for the final reduction

Own cases Of the 295 reduction cases in the present series local anaesthesia was given in 247 brachial block in 20 general anaesthesia in 16 and no anaesthesia in 10 In the remaining 2 cases a local anaesthesia proved insufficient to ensure a satisfactory reduction, whereupon a brachial block was administered in one case and a general anaesthesia in the other

Of the 31 cases in which Grath s (1956) extension apparatus was used for the primary reduction local anaesthesia was administered in 19 brachial block in 6 general anaesthesia in 2 and no anaesthesia in 4 Of the seven cases in which open reduction was performed (see above) this was done with a brachial block in six and a general anaesthesia in one There was one case in which brachial block was used for transfixation after closed reduction and immobilization in plaster had proved unsuccessful Brachial block was also used as a rule in the limited number of cases in which closed reduction was re attempted following re dislocation shortly after the primary reduction

Discussion There is no justification for using the results of reduction as an indication of the superiority of a particular form of anaesthesia The choice of anaesthesia should be dictated by the individual circumstances *In general it seems that satisfactory reduction of a fracture in the distal radius can be obtained in local anaesthesia* The analgesic effect of

a local anaesthesia in this type of fracture has been discussed for instance by Lidstrom (1959) As already mentioned a good 25 per cent of the patients in his series who underwent reduction in local anaesthesia spontaneously complained of having suffered severe pains during the manipulations In the present series in which 247 out of 295 cases were reduced in local anaesthesia alone only ten patients reported such complaints spontaneously A further indication that the analgesic effect is sufficient can be derived from the fact that local anaesthesia was usually employed even for relatively complicated manipulations such as reduction with an extension apparatus The other types of anaesthesia—brachial block and general anaesthesia—obviously have advantages in respect of analgesia and muscular relaxation, but their use is to some extent limited by the fact that these fractures are generally treated as out patient cases

Technique of immobilization

Lidstrom (1959) found that the technique of immobilization is undoubtedly the most controversial detail in the management of fractures of the distal radius The available literature contained a wide range of recommendations from a complete absence of fixation to large circular plaster bandages enclosing *the whole arm In general however the aim was to devise a means of fixation* that ensures satisfactory immobilization without preventing active movements of the fingers at an early stage In Lidstrom s own series the standard procedure was a dorsal plaster splint a circular plaster was used in only 12 cases with the elbow included in no more than two

Even in later publications there does not seem to be complete agreement about the ideal way of immobilizing fractures in the distal radius By and large however the dorsal plaster splint advocated by Bohler (1919 1923) still seems to be most common at least in Europe (Pehn 1965 Smaill 1965) At the same time there are still many authors who question this simple immobilization technique s effectiveness in preventing re dislocation Instead they propose the use of a circular plaster on the forearm (Guttman 1959 Schwetlick 1962 Soren 1965) Others go further and recommend the general use of a circular plaster extending above the elbow (Schnek 1962 Kudelka 1963 Sponsel 1964) Several authors wish to take the patient s age and the extent of the injury into consideration a circular forearm plaster being used for younger individuals with simple types of fracture and a plaster that also encloses the elbow for others Several American authors recommend a sugar tong plaster some of them together with a circular plaster bandage (Kenney 1960 Miller 1960 Kane 1964 Older Stabler & Cassebaum 1965)

Various methods of transfixation still seem to be in common use and are recommended in both the English and the German literature (Mack 1959 Kenney 1960 Miller 1960 Schnek 1962 Brady 1963 Kane 1964 Scott 1964) This is also true of fixation with Kirschner wires particularly for comminuted fractures (Willenegger & Guggenbuhl 1959 Boutin 1960 Older

Stabler & Cassebaum, Raschle 1965 Rehn 1965) Some authors indicate a preference for embedded Steinman pins which are introduced through the ulna in the direction of the radial styloid process (K P Madsen 1959 Dowling & Sawyer, 1961)

Elaborate methods for osteosynthesis appear to be recommended only for fractures that are particularly difficult to reduce and fixate Several authors mostly use a technique for closed reduction and fixation with Rush pins (Rush & Rush 1949) good results being reported with this treatment (Thornton & Warner 1955 Edwards 1959 Mack 1959) Other authors find it valuable in such cases to use open reduction and crossed Kirschner wires for fixation of the fragments (e g Jung & Heineman 1961)

Irrespective of the technique proposed for promoting fixation, these authors generally use some form of immobilization with plaster as well Rush & Rush (1949) however state that their technique for osteosynthesis imparts sufficient stability for immediate functional exercise

Own cases Some form of plaster support was used for fixation of the fracture in all but two of the 430 cases in the follow up examination No fixation at all was used in one case without reduction while in one reduced case fixation was achieved simply with an elastic bandage

A dorsal plaster splint was applied in the unreduced cases as well as in 174 of those in which reduction was performed a circular plaster being fitted in the other 120 cases It may be noted that closed reduction had been performed in the case in which only an elastic bandage was used for fixation while plaster was used in all the seven cases of open reduction as well as in the only case of transfixation *The elbow was included in the circular plaster in six of the 120 cases given this treatment the reason in each case being that the position of reduction was judged to be so unstable that forearm rotation had to be prevented in order to reduce the risk of re dislocation*

Duration of immobilization

In Lidström s (1959) series the period of immobilization lasted an average of 34 8 days simpler types of fracture generally having the shortest periods comminuted fractures and Smith's fractures the longest The majority of authors who have subsequently touched on this subject recommend a period of five or six weeks (Mack 1959 Kenney 1960 Hamsa 1962 Kudelka 1963 Waugh 1963) and recommendations to prolong the period of immobilization are also common (Guttman 1959, K P Madsen 1959 Drill 1963 Sponsel 1964 Older Stabler & Cassebaum, 1965) Only occasionally are reasons given for shortening this period to three (van Trappen 1964) or four weeks (Smaill 1965) Extreme proposals such as not using any immobilization at all (Lucas

Championnière 1886 Petersen 1894) do not appear to have been put forward in the literature in recent years

Own cases Immobilization lasted an average of 28 days for the entire follow up series Most of the fractures with or without dislocation were kept immobilized for four to five weeks fissure cases generally not more than two to three weeks while a few comminuted fractures were immobilized for as much as twelve weeks

These figures refer to the duration of continuous fixation A dorsal plaster splint was used in a few cases as a support during the night for the first week after the regular plaster had been removed

Position of the hand during immobilization

Lively interest used to be aroused by this subject as noted by Lidstrom (1959) in his review The chief questions were whether it is necessary to immobilize the hand in volar flexion and whether fixation in this position in fact involves a direct risk for the injured hand during the post traumatic course Lidstrom reported that in his series the wrist was immobilized as a rule in a neutral position if possible combined with ulnar deviation In only a few cases had the wrist been placed in a position of palmar flexion after the fracture had been reduced generally because it had been difficult to eliminate the dorsal angulation In all Lidstrom's cases the position of volar flexion was changed to one of extension after 10–14 days In keeping with Bohler (1919) several authors have recently condemned fixation in palmar flexion and ulnar deviation especially in such extreme forms as Cotton Loder s position In particular this position is considered to involve a considerable risk of compression of the median nerve as a result of constriction of the carpal tunnel (Abbot & Saunders 1933 Meadoff 1949 Robbins 1963) The position of fixation described by Bohler—with the extended wrist midway between pronation and supination combined with moderate ulnar deviation—still seems to be the one most generally accepted (Hamsa 1962 Kudelka 1963 Mandell 1965 Rehn 1965) Several authors however prefer a completely neutral position for the wrist i e midway between extension and flexion ulnar and radial deviation and pronation and supination (e g Soren 1965) Guttman (1959) and Mack (1959) also recommended a neutral position between extension and flexion for the wrist but in combination with ulnar deviation in other words the position for immobilization that was most common in Lidstrom s (1959) series

Own cases As already mentioned reduction was not performed in 135 cases in the present series One of these cases had no fixation in plaster at all while a dorsal plaster splint had been used in the other 134 In these cases the wrist was immobilized in slight dorsal flexion and ulnar deviation

All but one of the 295 reduced fractures in the series were immobilized with some type of plaster the exception being the case in which only an elastic bandage was used Of the 294 cases treated with plaster 195 had the wrist placed in a neutral position 82 had the wrist in volar flexion and 17 in dorsal flexion these positions were combined with ulnar deviation Volar flexion when used, was moderate and never more than 30° the indication in all cases being a clear risk of dorsal re dislocation the position was maintained for not more than 10-14 days after which the wrist was placed midway between flexion and extension In the case of immobilization in dorsal flexion, all 17 cases had had primary volar dislocation of the fracture

Physical therapy

There seems to have been a gradual decline in the popularity of the early, intensive physical therapy—with passive exercises massage and heat—that was frequently practised at the beginning of this century Such therapy has in fact been used in more recent series though generally on special indications only (Lidstrom 1959) Such indications were present in a good 25 per cent of Lidstrom s series and this group displayed considerably less satisfactory functional end results than the rest of the series According to Lidstrom no conclusion could be reached about the value of the physical therapy in his series except that it had no appreciable influence on the end result in the group in which it was used Otherwise there are only a few authors who discuss the justification for physical therapy in connection with fractures of the distal radius Older Stabler & Cassebaum (1965) and Smaill (1965) state that they use it only if the patient so wishes or under special circumstances such as when the fracture is complicated by a shoulder hand finger syndrome

The gradual abandonment of routine physical therapy for fractures of the distal radius occurred after Bohler (1919) stressed the value of active functional training In recent years there have thus been many authors who have indicated the desirability of carefully instructing the patient about active finger movements at the start of treatment strongly emphasizing the value of using the hand as much as possible for normal everyday tasks during the period of healing (Guttman 1959 K P Madsen, 1959 Kenney 1960 Djorup 1962 Hamsa 1962 Schwetlick 1962 Golden 1963 Kudelka 1963 Kane 1964 Sponsel 1964 van Trappen 1964 Older Stabler & Cassebaum, 1965, Paschle 1965 Rehn 1965 Smaill 1965 Soren 1965)

Active arm and shoulder movements in the form of daily exercises have previously not been ascribed the same importance as active finger exercises for avoiding complications during the treatment of fractures of the distal radius A sling is still widely used at least during the first week of immobiliza

tion More recently Moberg (1955) and others have pointed out the value of active arm movements for counteracting stiffness of the shoulder and swelling of the fingers after such fractures and this has subsequently been emphasized by several authors (Guttman 1959 Hamsa 1962 Golden 1963 Kane 1964 Sponsel 1964 Raschle 1965 Pehn 1965 Soren 1965)

Own cases All the patients in the present series were instructed at the start of treatment about intensive active exercises in the form of movements *of the shoulder and fingers The use of a sling was generally forbidden* In stead the patients were advised to perform *active elevation of both arms simul taneously to full extension at least 50 or 100 times a day* It is my opinion that this consistent regimen kept the need of physical therapy to a minimum in this series as witness the data provided in subsequent chapters and the separate review of the small number of cases with a shoulder hand finger syndrome

Physical therapy in the form of *active exercises supervised by a physical therapist* and limited to finger wrist and shoulder movements was given to only 11 patients in the present series Nine of these developed swelling of the fingers and a tendency to stiffness of the shoulder at an early stage of treat ment the physical therapy was consequently introduced while the patient was still in plaster mainly as a prophylaxis against the shoulder hand finger syndrome *In the other two cases physical therapy was given after the end* of immobilization to counter a loss of mobility in both the wrist and the forearm

As will be seen from the separate review of the shoulder hand finger syn drome only three of the nine cases given early physical therapy had a residual loss of function with impaired finger mobility and poor mobility in the wrist In the other six cases the active physical therapy may be said to have had a certain prophylactic effect Once again it should be pointed out that this therapy only involved active exercises and not passive movements massage or any form of heat treatment

hand In the follow up series roentgenograms taken at the end of treatment or later and showing a picture of healing in the fractures were available for a further 99 patients In these cases there was little possibility of comparing with the roentgen picture of the sound wrist However in order to gain some idea of the extent of shortening after the fracture had healed a similar comparison to that above was made between the first roentgenogram of the accepted reduction and the final pictures This procedure is not of course as accurate as Lidstrom s but it does give an approximate idea of the degree and the incidence of shortening when the fracture has healed

The total number of cases examined roentgenographically in the follow up series is thus 224 Their distribution by age sex and type of fracture was analysed to find out whether these cases were representative of the total follow up series (Table 11) A comparison with Table 6 p 37 (which gives the same distributions for the total follow up series) shows that there is good agreement on both counts This conclusion was supported by a statistical analysis of age and type of fracture as well as other factors of clinical importance The roentgen series has therefore been regarded as being representative of the total follow up series

The existence of any residual deformity in a volar or dorsal direction was determined from lateral view roentgenograms in the usual way A 10° volar angulation was taken as the normal position of the radial articular surface Deformities in a radial or ulnar direction were also measured using the decrease in the angle between the distal articular surface and the long axis of the radius in the frontal view

The distal radio ulnar joint was accorded particular attention in the roentgenological investigation especially in cases with clinical symptoms from this joint The roentgen examination comprised frontal projections in pronation and supination as well as lateral projections In order to permit measurement of the distance between the radius and the ulna in the distal radio ulnar joint the central ray in the frontal projection must be tangential to the articular surface of the radius in this joint To be sure of this it was necessary in most cases to angle the roentgen tube 2° 6° in an ulnar or radial direction in the frontal projections Besides making it possible to assess the distance between the radius and the ulna this procedure gave a better picture of the independently projected articular surfaces in the distal radio ulnar joint (Frykman & Scheller, 1962 1963)

Any post-traumatic articular changes in the radio carpal and distal radio ulnar joints were registered from both the general roentgenograms of the wrist and the specific roentgenograms of the distal radio ulnar joint In some cases (4 % of the roentgen series) such changes were also registered in other parts of the carpal skeleton

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Own cases Immobilization lasted an average of 28 days for the entire follow up series Most of the fractures with or without dislocation were kept immobilized for four to five weeks fissure cases generally not more than two to three weeks while a few comminuted fractures were immobilized for as much as twelve weeks

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As will be seen from the separate review of the shoulder hand finger syndrome only three of the nine cases given early physical therapy had a residual loss of function with impaired finger mobility and poor mobility in the wrist In the other six cases the active physical therapy may be said to have had a certain prophylactic effect Once again it should be pointed out that this therapy only involved active exercises and not passive movements massage or any form of heat treatment

CHAPTER VII

CASE REPORTS AND INVESTIGATION TECHNIQUES

Case reports

Written reports were available on all the patients in the follow up series They generally included a brief account of the accident as well as a report on the patient s condition at the time of admission to the hospital including the appearance of the wrist and any signs of disturbance in the innervation fields of the median ulnar and radial nerves Information was also provided on the post traumatic course including any subsequent neurological symptoms symptoms of the shoulder hand finger syndrome swelling of the wrist or fingers from other causes, tendon injury and the like Furthermore, the records showed how long immobilization in plaster had lasted and generally gave fairly exact information on when the patient resumed half or full time work Any persistent discomfort or disability had been recorded and copies were available of any certificate of disability providing valuable information about the patient s condition at the end of the treatment

Data at follow up

At the follow up interview, great importance was attached to ascertaining the patient s condition in the interval between the end of treatment and the time of the interview A note was made of any *aches and pains* during this period as well as any *neurological symptoms* In order to check the data in the case reports the patient was also asked whether neurological symptoms had appeared in conjunction with the trauma or early on during treatment and if so whether they had subsequently disappeared or persisted An accurate note was made of the time when such symptoms first appeared and whether they occured periodically Similar questions were asked about *symptoms of tendon rupture* in the long extensor to the thumb The patient's *present discomfort* was recorded with *questions about the presence of resting pain* the degree of this and any diurnal variation If pains were reported the patient was asked about their intensity location and spread Particular care was taken to determine whether any type of movement in the wrist elicited the pain or just rotation In this context the relation between pain on rotation and the size of a simultaneous load on the wrist was also studied

The patient was asked about *loss of mobility* i e whether stiffness of the wrist impaired forearm rotation or reduced mobility of the fingers was regarded as being a result of the injury The patient s subjective opinion about the *strength of the injured hand* was noted All patients were asked whether they were *right or left handed*

The patient s *working conditions* were gone into thoroughly Any transfer to a different type of work was noted special attention being paid to the tasks in the previous occupation that could not be performed on account of the persistent disability after the present injury

Clinical examination

The final assessment of the functional end results in the present series is based on a thorough clinical examination carried out in accordance with a pre determined plan In some cases however the examination was of an even more specialised nature (see below) The clinical examination comprised the following

1 *Inspection* Any swelling was noted The cosmetic appearance of the wrist was assessed and graded according to any visible dorso volar or radio ulnar displacement The two wrists were compared to evaluate the size of any increased prominence of the caput ulnae The appearance of the skin over the wrist and fingers was considered particular attention being paid to any scars after a compound fracture or surgery A note was made of any atrophy or other changes in the skin of the fingers in conjunction with impaired sudomotor function At the same time attention was paid to any signs of wear or work calluses on the injured hand in relation to the condition of the uninjured hand

2 *Palpation* Any tenderness was noted with particular reference to its relation to the radio carpal or the distal radio ulnar joint The latter joint was examined in each patient as follows The patient sat at a table opposite the investigator with the elbow resting on the table and the forearm held vertically in a relaxed position During manual compression of the distal radio ulnar joint the investigator executed passive supination and pronation In the extreme positions the loading pains described by the patient (especially those on rotation in the wrist) are clearly elicited Any crepitations in the distal radio ulnar joint were also noted during this examination (cf Moberg 1959)

In connection with the above examination the stability of the distal radio ulnar joint was tested with the technique described by Lidström (1959) The distal end of the radius was gripped between the thumb and forefinger of one hand while the thumb and forefinger of the other hand were used to

grasp the end of the ulna and try to move this to and fro in a dorso volar direction Any increase in the mobility of the distal end of the ulna on the injured side was registered

During palpation an attempt was also made to assess the degree of any persistent deviation that had escaped notice in the outward appearance of the wrist In addition a note was made of any large callus formation

3 *Active mobility of the wrist* The range of motion was measured with an ordinary goniometer and compared with the opposite hand In accordance with Cave & Roberts (1936) the neutral point was taken to be the position of the extended hand mid way between pronation and supination and with the palm flat against the palm of the other hand Mobility was measured with respect to dorsal flexion volar flexion ulnar deviation and radial deviation the same measurements in the uninjured hand being taken as the normal values In cases with bilateral fractures the values were compared with normal figures reported in the literature (Broman 1934) volar flexion 70° dorsal flexion 60°, ulnar deviation 45° and radial deviation 20° The range of pro and supination in the forearm was also tested, the upper arm with the forearm at right angles to it always being adducted into the body in order to avoid accompanying rotation at the shoulder Normal values were obtained in the same way as for the wrist (the total range of rotation being 150° according to Broman 1934)

As pointed out by Cobe (1928) the normal range of motion in the wrist varies between the sexes (greater in women) as well as within the same sex It may also differ between the wrists (greater in the left) Furthermore Cobe suggested that a single measurement cannot provide an adequate indication of the range of motion because active movements usually fall short of the joint s true capacity In addition comparisons with the opposite hand may be vitiated by earlier injuries in this which the patient has forgotten at the time of the examination On the other hand as Lidstrom (1959) pointed out even though this method of examination unquestionably has several sources of error it has to be accepted for practical reasons for lack of more exact methods of measurement on clinical series of this size

In view of these considerations the *passive range of motion* was measured as well in both the wrist and the forearm The results did not differ substantially from those obtained for the active movements In several cases this investigation elicited the same pain on motion as the patient had reported experiencing

4 *Strength of the grip* was measured with a Collin s dynamometer At least three measurements were made with each hand the average value being taken as a measure of the muscle power As many authors have pointed out the use of this dynamometer introduces considerable sources of error (Whipple,

1914 Brahme 1936 Lidström 1959 Mannerfelt 1966) Some of these were avoided as far as possible in the present investigation Thus the time factor between two consecutive measurements was reduced by having the investigator hold the manometer and place it in the patient s hand Since hardly any of the patients in this series had any pain in the hand itself there was little risk of the results being too low on this account The hand was dried with alcohol and ether before the measurement if there was a tendency to perspire strongly Even so one is of course left with the possibility that the dynamometer will be gripped incorrectly partly because the Collin s dynamometer does not automatically fit into the correct position This method of measurement may nevertheless be considered acceptable if one simply requires a rough estimate of the strength of the injured hand in relation to the sound one At all events no other method for determining the total strength of the hand is definitely known to be more exact

5 *Neurologic examination* The function of the musculature that is innervated by the median and ulnar nerves was tested as part of the routine examination as were the sensibility to pain and touch and the palpable sudomotor function in the areas of the hand that are innervated by the median ulnar *and radial nerves A ninhydrin test was made in all cases using the technique* described by Moberg (1958) This test added nothing of diagnostic interest to the findings on palpation but it did of course serve as a valuable objective indicator of loss of sudomotor function In the cases in which neurologic disturbances were noted in the innervation field of either the median or the ulnar nerve tactile gnosis was further examined with the aid of Moberg s (1958) picking up test and Weber s two point discrimination test

Roentgen examination

Primary roentgenograms were available for all the cases in the present series of 516 patients i e including those not treated by reduction In a few cases no roentgenograms had been taken before the reduction but the result of this had been checked roentgenographically In all cases therefore the type of fracture could be determined from primary roentgenograms taken before and immediately after reduction.

A roentgen investigation was conducted at the follow up examination in 125 of the 430 cases included in this In most instances roentgenograms were taken of both the injured and the uninjured wrist using a uniform focus film distance This made it possible to measure the shortening in the healed fracture of the radius as described by Lidstrom (1959) the degree of shortening is estimated by comparing the distance between a plane through the tip of the radial styloid process and a plane through the articular surface of the caput ulnae in the injured hand with the corresponding distance in the uninjured

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The total number of cases examined roentgenographically in the follow up series is thus 224 Their distribution by age sex and type of fracture was analysed to find out whether these cases were representative of the total follow up series (Table 11) A comparison with Table 6 p 37 (which gives the same distributions for the total follow up series) shows that there is good agreement on both counts This conclusion was supported by a statistical analysis of age and type of fracture as well as other factors of clinical importance The roentgen series has therefore been regarded as being representative of the total follow up series

The existence of any residual deformity in a volar or dorsal direction was determined from lateral view roentgenograms in the usual way A 10° volar angulation was taken as the normal position of the radial articular surface Deformities in a radial or ulnar direction were also measured using the decrease in the angle between the distal articular surface and the long axis of the radius in the frontal view

The distal radio ulnar joint was accorded particular attention in the roentgenological investigation especially in cases with clinical symptoms from this joint The roentgen examination comprised frontal projections in pronation and supination as well as lateral projections In order to permit measurement of the distance between the radius and the ulna in the distal radio ulnar joint the central ray in the frontal projection must be tangential to the articular surface of the radius in this joint To be sure of this it was necessary in most cases to angle the roentgen tube 2° 6° in an ulnar or radial direction in the frontal projections Besides making it possible to assess the distance between the radius and the ulna this procedure gave a better picture of the independently projected articular surfaces in the distal radio ulnar joint (Frykman & Scheller 1962, 1963)

Any post-traumatic articular changes in the radio carpal and distal radio ulnar joints were registered from both the general roentgenograms of the wrist and the specific roentgenograms of the distal radio ulnar joint In some cases (4 % of the roentgen series) such changes were also registered in other parts of the carpal skeleton

TABLE 11 *Distribution of age groups by type of fracture and sex in X ray series*

Age	Type of fracture																Total		
	I		II		III		IV		V		VI		VII		VIII				
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	Total
16–25	—	3	2	1	—	—	—	1	—	—	2	—	—	—	—	1	4 1 8%	6 2 7%	10 4 5%
26–35	—	1	3	—	1	2	1	1	—	1	1	—	—	—	1	—	7 3 1%	5 2 2%	12 5 3%
36–45	2	2	3	—	1	2	1	2	1	—	3	1	—	1	—	1	11 4 9%	9 4 0%	20 8 9%
46–55	5	1	6	—	3	4	1	2	4	1	11	2	—	—	6	1	36 16 1%	11 4 9%	47 21 0%
56–65	7	—	11	3	[illegible]	—	7	1	6	2	13	1	6	—	14	2	69 30 8%	9 4 0%	78 34 8%
66–75	13	1	8	1	2	1	9	1	1	—	4	—	—	—	10	1	47 21 0%	5 2 2%	52 23 2%
76–85	1	—	3	—	—	—	—	—	—	—	—	—	—	—	1	—	5 2 2%	—	5 2 2%
86–95	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Total	28 12 5%	8 3 6%	36 16 1%	5 2 2%	12 5 3%	9 4 0%	19 8 5%	8 3 6%	12 5 3%	4 1 8%	34 15 2%	4 1 8%	6 2 7%	1 0 4%	32 14 3%	6 2 7%	179 79 9%	45 20 1%	224
	36 16 1%		41 18 3%		21 9 3%		7 12 1%		16 7 1%		38 17 0%		7 3 1%		38 17 0%		224		

CHAPTER VIII

THE FOLLOW-UP STUDY

In my follow up study I found it suitable to consider the patient's subjective symptoms and the following objective factors (cf Lidström 1959) anatomical and cosmetic results loss of mobility loss of strength, neurologic signs and disturbance in the distal radio ulnar joint

The examinations were conducted according to the general methodological principles outlined in the preceding chapter Any special basis for assessments is reported below in the account of the objective findings

Subjective symptoms

Some kind of subjective symptom from the injured wrist or hand was reported in 225 of the 430 cases (52 3%) in the follow up study The symptoms were slight and scarcely affected function in rather more than half (122) of these cases They were reported more frequently by the women in the series (189 of 348 54 3%) than by the men (36 of 82 43 9%)

Discussion Only a few of the published reports discuss the incidence of subjective symptoms after fractures of the distal radius Edwards & Clayton (1929) found that in a series of 321 patients interviewed by questionnaire 73 2% reported no symptoms 23 1% moderate discomfort and 3 7% such pronounced discomfort that the function of the wrist was definitely impaired Lidstrom (1959) reported that 236 of the 515 patients (45 8%) in his follow up series had subjective symptoms from the injured wrist and that 133 of these regarded their symptoms as negligible Arbeitlang & Boeckl (1963) in a series of 201 cases reported subjective symptoms in 5 6% at the follow up examination Some cases had been examined after one year s observation the others after three years The incidence of subjective discomfort was said to be almost four times as high for the cases with the shorter observation period

There is thus a considerable variation in these incidences of subjective symptoms from different series I have not been able to find any explanation for this and can simply note that the incidence in the present series is similar to that in Lidstrom s both of which were selected in a similar manner and have much the same composition by age and sex

Weakness The most frequent symptom in the present series was *weakness of the hand and wrist* which was reported in 154 of the 225 cases with subjective symptoms The loss of strength was not as a rule particularly inconvenient but made itself felt when the patients tried to carry heavy loads or exerted the hand and wrist e g when opening a tin screw top jar or the like Many found it particularly troublesome when the hand was loaded with the forearm horizontal particularly if the forearm had to be rotated at the same time For example many housewives found it difficult to handle a frying pan or a saucepan with the injured hand Craftsmen (carpenters electricians) had similar difficulties in handling a screwdriver

Pain The next most frequent symptom was *pain in the wrist on loading* This was reported in 61 of the 225 cases The pain usually appeared as soon as the hand was loaded and rapidly disappeared when the load was removed In a few cases the pain was so intense that the object grasped by the hand had to be released

Another common subjective symptom was *pain on rotation* (59 of the 225 cases) This type of pain was generally moderate if the wrist and hand were not loaded but it increased at once when rotation was combined with weight bearing (This symptom was particularly frequent—49 out of 80 cases—in a group of patients having subjective symptoms as well as objective signs of disturbance in the distal radio ulnar joint)

An equally common symptom was *pain after exertion* which occurred in 58 cases with varying intensity and duration *Pain on a change in the weather* was reported in 23 cases Two cases of *continuous pain* were noted independent of any external factor (the pain being described as so severe that analgesics were required daily)

Excessive fatigability There were 10 cases with complaints of excessive fatigability of the hand and wrist unaccompanied by any other symptoms Strains on the wrist which had been tolerated before the injury now elicited a sensation of fatigue in the arm

Loss of mobility in the wrist was reported in 12 cases ten of the patients having noticed a dorso volar impairment and two a less satisfactory rotation in the forearm and wrist This low incidence of 12 cases with subjective reduction of the range of movements in the wrist contrasts strongly with the objective findings for the series—impaired mobility of the wrist in 332 cases

Swelling after exertion was reported in six cases though this could not be verified at the objective examination

Neurological symptoms were indicated in 14 cases in the form of reduced sensibility to pain and touch or tingling in the innervation field of the median or the ulnar nerve A feeling of clumsiness in the injured hand accompanied this impaired sensibility in three of the cases

Locking None of the patients reported symptoms of *locking in the wrist during pronation or supination* This seems remarkable in view of the fact that no less than 80 cases had objective signs of disturbance in the distal radio ulnar joint

Discussion

My series presents a wide range of subjective symptoms The most common was weakness of the hand and wrist This was the most common symptom in Lidström s (1959) series too and the incidences of the other symptoms are also much the same in both studies

Objective findings

Anatomical end results

In keeping with Lidstrom (1959) I have assessed the anatomical end results as follows

(1) No or insignificant deformity dorsal angulation not exceeding 90° or shortening of less than 3 mm

(2) Slight deformity dorsal angulation of 91–100° and/or shortening of 3–6 mm

(3) Moderate deformity dorsal angulation of 101–114° and/or shortening of 7–11 mm

(4) Severe deformity dorsal angulation of at least 115° and/or shortening of at least 12 mm

Only 224 of the 430 cases in the present series were given an x ray examination at a time when the fracture could be considered healed (cf Chapter VII p 56) These 224 cases have been shown to constitute a representative sample of the follow up series and consequently the following assessment of their anatomical end results may be held to apply to the entire series

The anatomical end results for the series are given in Table 12 Cases without residual deformity make up 25% of the series and cases with severe deformity 5%

The table also shows the anatomical end results in relation to type of fracture The only definite conclusion to be drawn from this is that less satisfactory anatomical end results are obtained regardless of the nature of the distal radius fracture when there is also a fracture in the distal ulna Thus the anatomical end result (angulation and shortening) does not seem to be influenced by whether the fracture is intra articular or extra articular

The 80 cases with disturbance in the distal radio ulnar joint are analyzed in Chapter XI in the same way as the total series It is nevertheless interesting to consider here the anatomical end results for the 70 cases in this group that

TABLE 12 *Anatomical end results in relation to type of fracture (total X ray series)*

	Type of fracture																
	I		II		III		IV		V		VI		VII		VIII		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	Total
No deformity	13	36	13	32	7	33	5	18	5	31	9	21	1	14	5	13	57 25%
Slight deformity	16	45	15	36	12	57	11	41	7	44	14	37	3	43	16	42	94 42%
Moderate deformity	7	19	11	7	2	10	10	37	4	25	12	32	3	43	13	34	62 28%
Severe deformity	—	—	2	5	—	—	1	4	—	—	4	10	—	—	4	11	11 5%
Total	36	100	41	100	21	100	27	100	16	100	39	100	7	100	38	100	224

had been given a final x ray examination These results are shown in Table 13 for the group as a whole as well as in relation to type of fracture Compared with the total x ray series above there is a smaller proportion of cases without residual deformity and almost double the proportion of cases with severe deformity The tendency for anatomical end results to be less satisfactory if the distal radius fracture is accompanied by fracture in the distal ulna is also evident in this group

Discussion The anatomical end results in this series largely agree with those reported by Lidström (1959) The distributions by degree of deformity are thus approximately the same and the anatomical end results are less satisfactory for the types of distal radius fracture that include fracture in the distal ulna The reason for the poorer results for these types of fracture is that the primary dislocation was probably more pronounced and the tendency to re dislocation greater

Cosmetic end results

The cosmetic end results in the present follow up series were assessed in relation to the four groups used by Lidstrom (1959)

(1) Normal appearance

(2) Normal appearance except for prominence of the capitulum (caput) ulnae

(3) Slight radial deviation

(4) Moderate to pronounced radial deviation silver fork deformity

The cosmetic end results assessed in this way are given in Table 14 for the follow up series A normal appearance was found in 49% of the cases and pronounced deformity in 5% In general the cosmetic results appear to to be worse if the distal radius fracture is accompanied by a fracture in the distal ulna The cosmetic results are also clearly inferior for the intra articular types of fracture compared with the extra articular The degree of intra articular involvement also seems to have some negative effect on the cosmetic results

Since an important point in the present series is the relationship between the cosmetic and the anatomical results the former are given in Table 15 for the 224 cases in which a final x ray examination was performed The cosmetic results are here worse than in the follow up series e g the proportion of cases with a normal appearance is 11% lower although the proportion of cases with pronounced deformity is much the same The deleterious effect of an accompanying fracture in the distal ulna is even more marked in the x ray group On the other hand intra articular involvement does not appear to affect the cosmetic result in this group in contrast to the results for the total follow up series

TABLE 13 *Anatomical end result in relation to type of fracture (cases with disturbance in the distal radio ulnar joint)*

	Type of fracture																
	I		II		III		IV		V		VI		VII		VIII		Total
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
No deformity	1	50	3	50	—	—	—	—	2	25	6	27	—	—	—	—	12 17%
Slight deformity	1	50	3	50	5	100	1	25	3	37 5	5	3	2	50	9	47	29 41%
Moderate deformity	—	—	—	—	—	—	2	50	3	37 5	8	36	2	0	8	42	23 33%
Severe deformity	—	—	—	—	—	—	1	25	—	—	3	14	—	—	2	11	6 9%
Total	2	100	6	100	5	100	4	100	8	100	22	100	4	100	19	100	70

TABLE 14 *Cosmetic end results in relation to type of fracture (follow up series)*

	Type of fracture																
	I		II		III		IV		V		VI		VII		VIII		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	Total
Normal appearance	56	73	37	47	27	61	21	39	16	52	[illegible]8	39	3	2[illegible]	21	35	209 49%
Prominent cap ulnae	8	10	5	6	4	9	6	11	3	10	5	7	1	7	2	3	34 8%
Slight radial deviation	13	17	33	42	13	30	24	44	11	35	29	41	9	64	31	5[illegible]	163 38%
Silver fork deformity	—	—	4	5	—	—	3	6	1	3	9	13	1	7	6	10	24 5%
Total	77	100	79	100	44	100	54	100	31	100	71	100	14	100	60	100	430

TABLE 15 *Cosmetic end results in relation to type of fracture (total X ray series)*

	Type of fracture																Total
	I		II		III		IV		V		VI		VII		VIII		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
Normal appearance	24	67	13	3	[illegible]	57	8	30	5	31	11	28	1	14	11	30	[illegible] 38%
Prominent cap ulnae	2	5	4	10	2	10	4	15	2	13	3	8	—	—	2	5	19 9%
Slight radial deviation	10	[illegible]	[illegible]	53	7	33	13	48	9	56	18	46	5	72	[illegible]	54	104 46%
Silver fork deformity	—	—	2	5	—	—	2	7	—	—	7	18	1	14	4	11	16 7%
Total	36	100	41	100	21	100	27	100	16	100	39	100	7	100	37	100	[illegible]

TABLE 16 Cosmetic end results in relation to type of fracture (cases with disturbance in the distal radio-ulnar joint of X-ray series)

	Type of fracture																Total
	I		II		III		IV		V		VI		VII		VIII		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
Normal appearance	1	50	2	33	1	[illegible]	2	50	1	12.5	5	22	—	—	5	28	17 21%
Prominent cap. ulnae	—	—	1	17	—	—	—	—	1	12.5	1	4	—	—	1	5	4 6%
Slight radial deviation	1	50	3	50	4	80	1	[illegible]	6	75	10	44	4	100	9	50	38 54%
Silver fork deformity	—	—	—	—	—	—	1	25	—	—	7	30	—	—	3	17	11 16%
Total	[illegible]	100	6	100	[illegible]	100	4	100	8	100	23	100	4	100	18	100	70

Table 16 gives the cosmetic results for the 70 cases out of the 80 with disturbance in the distal radio ulnar joint that were given a final x ray examination (i e the group considered separately under Anatomical end results) In general the cosmetic results were considerably inferior to those for the total group given a final x ray examination There is no indication that an ulna fracture or an intra articular involvement of the distal radius fracture has an unfavourable effect on the cosmetic end results

Discussion With the criteria used here the only direct comparison that can be made between the anatomical and the cosmetic end results is in respect of severe deformity While there is good agreement between the two for the total group given a final x ray examination the smaller group with disturbance in the distal radio ulnar joint has less satisfactory cosmetic results compared with the anatomical in this respect This relationship in the smaller group probably reflects the fact that under certain conditions even moderate anatomical deformity is liable to produce the appearance of a silver fork deformity In both groups however the cosmetic results as a whole are inferior to the anatomical results even though both have more cases with excellent cosmetic results than with excellent anatomical results This is certainly due to the frequency with which in particular minor anatomical deformity with slight shortening impairs the cosmetic result through a prominent caput ulnae or more often a slight radial deviation On the other hand the greater number of excellent cosmetic results compared with excellent anatomical results in both groups indicates that even relatively severe anatomical deformity is often not apparent from the cosmetic appearance

Even though there are apparently some minor differences between the cosmetic and the anatomical end results in this series there is considerable agreement between them in general The cosmetic results like the anatomical seem to be adversely affected by the combination of the distal radius fracture with a fracture of the distal ulna The explanation for this is no doubt the same for both types of result and has been discussed in connection with the anatomical results above

The cosmetic results in my series were assessed as already mentioned with the same criteria as in Lidström s (1959) study His findings were more favourable than those reported here with normal appearance in 60% of the cases and silver fork deformity in 11%

Lidstrom too reported general agreement between the anatomical and the cosmetic results even though many cases of considerable anatomical deformity had no corresponding cosmetic impairment He considered that this partly depended upon the amount of soft tissues but chiefly upon the type of deformity which dominated the roentgenogram Thus he found that Dorsal angulation not exceeding 105 if it was the sole residual deformity often did

not cause any clinical signs. Mere telescopic shortening of the radius without significant radial deviation of the articular surface similarly caused extremely slight cosmetic changes. In some cases, on the other hand, where the roentgenograms bore evidence of a perfect anatomical result, the cosmetic result was marred by a prominent capitulum ulnae. In many cases this was due to a soft-tissue injury in the distal radio-ulnar joint causing the end of the ulna to displace ulnarwards and palmarwards.'

Information about cosmetic results in earlier series is provided in different ways in the relatively few reports in which it is included. Rosenbach (1902) found no deformity in 70% of his cases and 10% severe deformity. Kotrnetz & Geiringer (1937) report perfect cosmetic results in 58.6%, good in 24.6%, acceptable in 12.5% and poor in 4.3%. Hoffmann (1953) found good cosmetic results in 43% and poor in 26%, while Mason (1953) only reports that 70% had satisfactory results. These figures thus appear to correspond to those reported for my series or by Lidström.

Loss of mobility

Loss of mobility was registered in my series if it exceeded 10° in any direction at the wrist. As shown in Table 17, no less than 77% of the cases had a loss of at least this magnitude. The incidence is clearly higher for the distal radius fractures accompanied by fracture of the distal ulna, regardless of whether the former fracture was extra-articular or intra-articular. There is no substantial difference between the incidences for extra-articular and intra-articular types of fracture, except that loss of mobility tends to be more common if the fracture involves both the radio-carpal and the distal radio-ulnar joint.

It will be seen from Table 18 that the most common form of impaired mobility was reduced volar flexion (52%), followed by reduced ulnar deviation (40%). Impaired supination was almost four times as frequent as impaired pronation.

TABLE 17. *Incidence of impaired mobility in relation to type of fracture (Follow-up series.)*

	Type of fracture								
	I	II	III	IV	V	VI	VII	VIII	Total
Incidence of cases with impaired mobility	51/77 66%	63/79 80%	34/44 77%	43/54 80%	20/31 64.5%	58/71 82%	11/14 79%	52/60 87%	332/430 77%

TABLE 18 *Loss of mobility (follow up series)*

Loss of	10–19	20–29	30–39	40–49	50–59	Total	
	No of cases					No	%
Volar flexion	13[illegible]	68	20	3	—	223	[illegible]
Dorsiflexion	9[illegible]	18	6	—	2	1[illegible]	[illegible]8
Ulnar deviation	127	44	1	1	—	1[illegible]3	40
Radial deviation	76	12	2	—	—	90	21
Pronation	13	4	1	—	1	19	4
Supination	49	11	4	1	1	66	15

The different forms of impaired mobility were present together in the majority of cases only a small proportion having simply impaired palmar flexion or impaired dorsal flexion

As reported in the table the loss of mobility was found to be generally moderate i e less than 20

Three of the 430 cases (0 7%) in the series presented *loss of mobility in the fingers* In each case this was due to shortening of the collateral ligaments in the metacarpophalangeal and interphalangeal joints All three cases represented residual symptoms after a shoulder hand finger syndrome They all presented some diastasis between the finger tips and palm at maximal clenching of the fist (Partly owing to these defective movements all three cases were classified under poor functional result)

No cases in the present series displayed impaired shoulder mobility as a sequela of the distal radius fracture or a shoulder hand finger syndrome if present

Discussion Previous authors differ somewhat over the degree of restricted mobility that is compatible with a satisfactory functional result In general however less than 10° loss of mobility is not registered (Wiklund & Mullern Aspegren 1956 Lidström 1959 Arbeitlang & Boeckl 1963 van Trappen 1964) The incidences reported for loss of mobility after distal fractures of the radius vary a great deal Graham (1938) found 50% with impaired volar flexion and 17% with impaired supination Bacorn & Kurtzke (1953) in a large series of compensation cases found impaired palmar flexion in 94.5% of the cases and limited pronation and supination in one third Lidstrom (1959) reported loss of mobility in 48 5% of his cases but Arbeitlang & Boeckl (1963) in only 21 9% of theirs The incidence in my series is thus higher than that generally reported previously While there is no apparent explanation for this difference it may of course reflect differences in the technique of examination

In Lidström's series about one fifth of the patients had observed the loss of mobility themselves In this respect there is a further discrepancy in my series in which only 12 of the 332 cases concerned patients who had themselves noticed the loss of mobility

Lidstrom found that the incidence of impaired mobility was lower for simple fractures of the distal radius while the group with comminuted fractures had an incidence of about 80% No direct comparison in this respect can be made with my results because the fractures are classified differently

Only 0 7% of my series had loss of finger mobility that could be attributed to the distal radius fracture or its sequelae The figure in Lidstrom s series was 4% though the impairment was relatively slight in most cases Since some of these cases also presented clinical signs of rheumatoid arthritis, Lidström questioned whether the loss of finger mobility was due to the distal radius fracture in every case Whatever the cause the present incidence must be considered unusually low compared with those in other series, e g 20% in Graham's (1938)

Loss of strength

The strength of the grip was in my series determined with a Collin s dynamometer Three consecutive measurements were made their mean being taken as the strength of the grip Several authors have pointed out that the use of this type of dynamometer is subject to considerable sources of error (Whipple, 1914 Brahme 1936 Lidström 1959 Mannerfelt 1966) As mentioned in a previous chapter some of the disadvantages indicated by Mannerfelt were avoided as far as possible in the present study—the interval between measurements was minimized by the investigator himself placing the manometer in the patient s hand and the hand was dried with alcohol or ether if there was a pronounced tendency to perspire

The strength of the injured hand was compared with that of the other i e the healthy hand Seven patients however had bilateral fractures Four of them had a definite loss of strength in the leading hand whereas the strength of their non leading hand could be accepted as quite normal Since it was possible to make this assessment these four cases have been included in the results for the total series The other three patients with bilateral fractures had no signs of impaired strength in either hand Nor were there any cases with previous injuries that might render the other hand invalid for such a comparison

The criteria used in the present study for loss of strength were (1) *Strength in an injured leading hand less than that in the non leading hand* and (2) *Strength in an injured non leading hand less than half that in the leading hand*

On this basis loss of strength was found in 102 of the 430 cases (24%) in the total follow up series Table 19 shows the results in relation to age and type of fracture It will be seen that loss of strength appears to be less frequent after extra articular fractures than after intra articular while among the latter the frequency is approximately the same irrespective of the type or degree of the intra articular involvement The youngest and oldest age groups have the lowest incidences for loss of strength while the incidence is somewhat higher and much the same in the middle age groups (46–55 and 56–65 years)

The incidence of loss of strength shows no difference between the sexes The incidence for fractures in the left wrist was 12% whereas that for the right wrist was 41% This difference is hardly surprising however since 417 of the cases (97%) concerned right handed patients

Functional disturbance in the distal radio ulnar joint clearly contributed to loss of strength in the hand This is shown by Table 20 which relates loss of strength to age and type of fracture for the 80 cases with such disturbance The incidence here is 45% compared with loss of strength in 24% of the total follow up series Again there is a higher incidence among the intra articular compared with the extra articular fractures though the difference is not so pronounced as in the total series

Nor do these 80 cases show any sex difference in the incidence of loss of strength The difference between the hands however is still more pronounced the incidence of loss of strength after fractures in the left hand being 24% and after fractures in the right hand 68%

TABLE 19 *Incidence of impaired grip strength in relation to age and type of fracture (Follow up series)*

Age	Type of fracture								Total	
	I	II	III	IV	V	VI	VII	VIII	Incidence	%
16–25	—	2	—	—	—	1	—	1	4/23	17
26–35	—	—	2	—	—	—	—	—	2/21	9.5
36–45	4	—	1	1	1	1	—	—	8/39	20.5
46–55	4	2	3	1	4	8	1	3	26/85	31
56–65	3	5	4	6	2	8	2	7	37/142	26
66–75	4	2	2	4	1	5	1	3	22/105	21
76–85	1	1	—	—	—	—	—	—	2/14	14
86–95	—	—	—	—	—	1	—	—	1/1	(100)
Total incidence	16/77	12/79	12/44	12/54	8/31	24/71	4/14	14/60	102/430	
%	21	15	27	22	26	34	28	23	24	

TABLE 20 *Incidence of impaired grip strength in relation to age and type of fracture (Cases with disturbance of the distal radio ulnar joint)*

Age	Type of fracture								Total	
	I	II	III	IV	V	VI	VII	VIII	Incidence	%
16–25	—	—	—	—	—	1	—	1	2/2	100
26–35	—	—	—	—	—	—	—	—	0/[illegible]	0
36–45	—	—	—	—	—	1	—	—	1/3	33
46–55	—	1	—	—	2	5	—	2	10/19	53
56–65	1	1	[illegible]	1	1	4	1	7	18/38	47
66–75	—	—	—	—	—	3	—	2	5/14	36
76–85	—	—	—	—	—	—	—	—	0/2	0
86–95	—	—	—	—	—	—	—	—	—	—
Total incidence	1/3	2/6	2/6	1/4	3/9	14/25	1/5	12/22	36/80	
%	33	33	33	25	33	56	20	54	45	

Discussion Only Lidström (1959) appears to have reported any direct figures for the incidence of loss of strength in the hand after fractures of the distal radius Since he used much the same examination technique and similar criteria for assessing the loss of strength his results appear suitable for a comparison with those reported here

Compared with an incidence of 24% in my series Lidström reports loss of strength in 17 5% of his series My series displayed a good correlation between subjective symptoms of loss of strength and the results of objective measurement No less than 65 of the 102 cases (64%) with a measurable loss of strength also had subjective symptoms of this In Lidström s series on the other hand only 16 out of 84 patients had themselves noticed that the strength of the injured hand was impaired Lidström found a higher incidence of impaired strength among fractures with complete displacement the highest figure referring to the group with comminuted fractures No such relationship could be discerned in my series On the other hand a higher incidence was found for intra articular types of fracture compared with extra articular It is also interesting that the cases with symptoms of disturbance in the distal radio ulnar joint have a considerably higher incidence of impaired strength than those without such symptoms

Neurologic signs

As already mentioned all the cases in the present follow up series were examined with particular care for any neurologic symptoms that might be

related in some way with the fracture of the radius either as a direct result of the accident or as sequelae

Subjective symptoms of loss of sensibility in the innervation field of the median nerve were reported in 10 cases eight of which also presented objective signs of impaired sensory function of this nerve In three of the cases there was also atrophy and loss of strength in the thenar muscles

In all eight cases in which the subjective symptoms were confirmed objectively the hand function was impaired to such an extent that it adversely affected the functional end result

Subjective symptoms of loss of sensibility in the innervation field of the ulnar nerve were reported in 4 cases three of which also presented objective signs of impaired sensory function None of these cases however showed signs of impaired motor activity of the ulnar nerve

The three cases with subjective symptoms and objective signs of injury to the ulnar nerve all displayed an inferior functional end result partly as a consequence of the impaired function of this nerve

The cases with primary and late injuries to the median and ulnar nerves are discussed in a separate section in Chapter XI

Tendon injuries

Injury to the tendon of the extensor pollicis longus muscle was found in three of the 430 cases (0 7%) in the follow up series The subcutaneous tendon rupture occurred within about two months of the accident in two cases and later than this interval in one case

One of the e cases was treated surgically with satisfactory function at the follow up examination In one of the other two the rupture was discovered before the end of treatment for the fracture but the patient refused surgical treatment In the third case the patient had not applied for treatment of the rupture although impaired extension of the thumb of the injured hand had been noticed In both the last two cases the tendon rupture clearly caused the patient difficulty through impaired pinching power and impaired gripping capacity The rupture definitely contributed to the unsatisfactory functional end result in these cases

The subcutaneous rupture of the tendon to extensor pollicis longus in this series is considered in a separate section in Chapter XI

Disturbance in the distal radio ulnar joint

Several references have already been made to the 80 cases (18 6%) in my series in which there were clinical signs of disturbance in the distal radio ulnar joint This group is also discussed in detail in Chapter XI

CHAPTEP IX

CRITERIA FOR EVALUATION OF THE FUNCTIONAL END RESULTS

Considering that distal fracture of the radius is a relatively well defined type of fracture and that except for a few minor deviations its treatment is fairly uniform one would hardly expect to find large differences between the results of treatment in published series And yet such differences do exist Some authors regard this type of fracture as difficult to treat, with a rather poor prognosis (Miller, 1960 Golden 1963 Rehn 1965 and others) Grasby & Trick (1929), for instance found poor results in 62 5 % of their series of patients with primary dislocated fractures In a series of compensation cases, Bacorn & Kurtzke (1953) reported a 24 % average disability (range 0–100 %) with only 2 % of the cases displaying entirely satisfactory results In contrast to these discouraging figures other published series are reported to have a satisfactory functional result in considerably more than 90 % of the cases (e g Krantz 1910 Eklund, 1927 Platt, 1932 Kotrnetz & Geiringer, 1937 Cassebaum 1950 Mason 1953 Djorup, 1962 and Schnek 1962) Outstandingly favourable figures have been reported by Ehalt (1935) from Bohler s clinic with satisfactory function in almost 100 % of the cases

Lidström (1959) is one of those who have discussed the reasons for the large differences between the results in published series He considers no doubt correctly that the explanation has less to do with variations in and the quality of the treatment than with the use of different criteria for evaluation of the residual symptoms and clinical findings at the follow up For one thing no significant correlations can be demonstrated between variations in the result of treatment and different therapeutic techniques whereas one soon finds that very slight modifications of the criteria used to assess the end result may produce very considerable changes in the analysis of results As an example of this Lidstrom cites two authors different criteria for evaluating the residual loss of mobility in the wrist One of them (E Madsen 1949) considered a 15° loss of palmar flexion incompatible with a satisfactory functional result whereas the other (Cassebaum 1950) accepted the same loss in his requirements for an excellent result In most publications moreover both the objective findings and the patient s subjective evaluation contribute to the assessment of the functional end result which will consequently vary with the inter

pretation of the patient s statements It is well known from Lidström s mono graph—and is clear from the present study—that some patients tend to minimize their subjective complaints, ignoring quite considerable cosmetic defects as well as loss of mobility provided that their wrist does not prevent them from doing the same tasks as before the injury Nor does Lidstrom find this surprising since many unskilled tasks including household work do not require the full range of motion of the wrist While pointing out that a serious loss of mobility even though unnoticed by the patient should lead to the case being classified as unsatisfactory Lidstrom warns against grading the functional end result too strictly in accordance with a moderate loss of motion Thus he considers that a 25° loss of palmar flexion does not necessarily con stitute an unsatisfactory end result in a patient with no other objective find ings and no subjective symptoms In conclusion, Lidstrom remarks that any final evaluation of the functional end result must inevitably represent a compromise

Lidstrom classified his end results under four headings namely *Excellent Good Fair* and *Poor* (see below) and found that in his series of 515 cases 41 5 % had Excellent results 38 % Good 12 % Fair and 8 5 % Poor

The end results in the present follow up series of 430 ca es were assessed with much the same criteria as Lidstrom used The four headings and their criteria are given below with the additions to Lidstrom s criteria shown in italics

1 *Excellent results* Function of the wrist unimpaired No subjective symp toms No deformity Loss of dorsiflexion or palmar flexion not exceeding 15° accepted *No loss of strength*

2 *Good results* Function of the wrist unimpaired Negligible subjective symptoms Deformity accepted if not producing subjective symptoms *Mode rate loss of motion i e up to 20° though a loss of 25 accepted as a solitary symptom Slight to moderate loss of strength accepted i e if leading hand only slightly weaker than other hand, if non leading hand not less than half of leading hand*

3 *Fair results* Function of the wrist less satisfactory for activities requiring special strength or extreme movements which must be avoided Most pre injury activities possible Loss of motion even if marked accepted if not associated with subjective symptoms *Moderate loss of strength accepted i e if leading hand definitely weaker than other hand if non leading hand less than half of leading hand*

4 *Poor results* Working capacity diminished or general way of life affected Cases with continuous pain *Considerable loss of strength i e if leading hand considerably weaker than other hand if non leading hand considerably less than half of leading hand*

In the series reported in the literature the systems used for classifying the end results have not included any of the special subjective and objective symptoms associated with sequelae of a fracture in the distal radius, i e disturbance of the distal radio ulnar joint nerve injuries the shoulder hand finger syndrome and tendon injuries While this seems reasonable in general since these symptoms are any way incorporated in the criteria, there are cases in which they occur separately, with a clear effect upon the end result In the present series special consideration was paid to this point (cf Chapter X)

CHAPTER X

FUNCTIONAL END RESULTS

Judged by the criteria presented in Chapter IX the present series displayed the end results compiled in Table 21

Discussion

These end results show more residual disability than those presented by for instance Lidström (1959) This is remarkable considering that the present series includes a number of cases of fracture without primary dislocation According to the current opinion in the literature one would rather expect their presence to increase the number of satisfactory end results That this was not the case is partly due to the use of a somewhat different classification compared to other published series but more especially to the fact that in certain cases special consideration was paid to symptoms occasioned by the sequelae as specified in Chapter IX This aspect will be discussed at greater length in Chapter XI in connection with the analysis of the factors that are significant for the end results

Here it may be noted that the present results like those in for instance Lidstrom s series occupy an intermediate position between the best and the worst in the literature In Lidstrom s series there were only a few cases in which the fracture resulted in permanent disability while in about 10 % of the cases the loss of function did not impair the individual s ability

TABLE 21 *End results in the total follow up series*

Result		No of cases	%
Excellent		105	24
Good		218	51
Fair		81	19
Poor		26	6
	Total	430	100

to work after the injury had healed In the present series there was a somewhat smaller proportion of cases with permanent disability but almost 20 % of the individuals had fairly considerable subjective discomfort and impeded function Even so I consider that the end results in the present series may be regarded as relatively good

It should be strongly emphasised that, even though the number of cases with a poor functional end result may not appear very large in a series of this type, the high incidence of fractures in the distal end of the radius means that every year a large number of patients are disabled to a greater or lesser extent as a result of this injury

CHAPTER XI

END RESULTS AND THEIR DEPENDENCE ON CERTAIN CLINICAL VARIABLES

Distal fracture of the radius in adults is generally considered to have an incidence of 10–20% of all clinical forms of fracture (M Hirsch 1914 Bohler 1919 Hilgenfeldt 1950 Robbins 1950 Wiklund & Mullern Aspegren 1956 and others) The annual incidence of such fractures in Sweden has been estimated to 5000 (Lidstrom 1959) a figure that agrees quite well with a reported incidence of between 2500 and 3000 for Finland (Valtonen 1949) On the other hand both these figures are low in relation to the findings of Alffram & Bauer (1962) in a five year series in Malmö (pop c 200 000) there were about 300 cases annually of distal fractures of the radius in adults Raised to a total population of 7½ million this gives an incidence of about 12 000 cases annually in Sweden

From the present study and other published series of consecutive cases it seems that unsatisfactory end results are generally found in 20 to 25% of fractures of the distal radius The common occurrence of this type of fracture thus means that a considerable number of cases annually incur practical social consequences as a result of varying degrees of permanent invalidity Several factors contribute to this *Those which I consider most important will be subjected to a clinical analysis in this chapter*

Of the 430 cases in the follow up series 295 had the fracture reduced after which the wrist was immobilized either with a dorsal plaster splint or with a circular forearm plaster usually in the 180 position (i e in line with the forearm) and in slight ulnar deviation In 6 cases the elbow was included in the circular plaster The reduction technique was more or less uniform throughout with the exception of 7 cases in which open reduction was performed Nor was there any large variation in the duration of immobilization The principles of treatment in the reduced and un reduced cases were otherwise the same Minor variations in this respect had no demonstrable influence on the end results and are consequently not considered in the clinical analysis below

The factors that seem to call for an analysis in relation to the end results are as follows

A *General factors* (1) Age (2) Sex (3) Type of fracture (4) Fracture of

caput ulnae or ulnar styloid process (5) Anatomical end result (6) Interval between accident and follow up study

B *Special factors (including sequelae)* (1) Injuries to the distal radio ulnar joint (2) Nerve injuries (3) Shoulder hand finger syndrome (4) Rupture of the extensor pollicis longus tendon

A1 Age

Some authors consider that between the ages of 40 and 70 the results are largely independent of age but that below the age of 40 they are better and above the age of 70 they are worse (Rosenbach 1902 White 1940 van Trappen 1964 Older Stabler & Cassebaum 1965) Hitzrot & Murray (1921) found that the results deteriorated above the age of 50 while Golden (1963) reported that age affected the end results only in patients of 70 or over Better end results in younger age groups are reported by Eskelund (1927) while Ehalt (1935) found similar re ults regardless of the patient s age though the period of treatment was shorter among younger individuals

Bacorn & Kurtzke (1953) provide the interesting finding that in their compensation cases the degree of invalidity rose by 4% per 10 year age group Glock Mackel & Brown (1957) al o state that residual invalidity is directly proportional to the patient s age Although Lidström (1959) found that the results in his series were better in the under thirties and worse in the over seventies he could not detect any definite trend towards a variation with age Moreover the differences between the age groups in his series were generally small In view of the fact that the majority of his patients were in the age group 50–70 years Lidstrom drew the conclusion that the age factor was of minor importance for the ultimate function of the wrist The number of redisplacements did however increase with age leading to somewhat less sati factory anatomical results Somewhat surprisingly this did not give rise to less satisfactory end results in the higher age groups According to Lid strom this was partly because the redisplacement was slight in most cases and partly because demands on the function of the wrist are lower in elderly people who consequently report fewer subjective symptoms

Own cases Table 22 and Fig 24 give the relations between the functional end results and the patients age at the time of injury The functional results are fairly uniform in the age groups under 45 though the youngest age group has relatively fewer unsati factory results Nor are there any major differences between the three middle age groups from 45 to 75 years In the two highest age groups the number of unsatisfactory results is somewhat greater than in the others In general though the differences in functional end results between the age groups are rather slight The only possible age dependent trend is

TABLE 22 End results in relation to age (follow up series)

Result	Age in years																Total no of cases	
	10 25		26 35		36–45		46 55		56 65		66 75		76 85		86 95			
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%
Excellent	10	43	8	39	16	41	10	19	30	°1	25	74	—	—	—	—	105	4
Good	11	48	10	17	18	16	47	55	67	47	5	5'	10	71	—	—	218	51
Fair	2	9	2	10	3	8	16	19	33	3	°0	10	4	29	1	100	81	19
Poor	—	—	1	5	2	5	0	7	1‿	0	6	6	—	—	—	—	26	6
Total	3	100	21	100	39	100	85	100	11‿	100	105	100	14	100	1	100	430	100

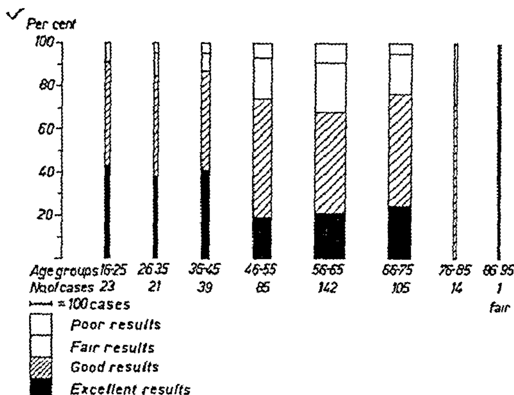


Fig 24 End results in relation to age

that for all three age groups under 45 in relation to the three between 46 and 75 years The top two groups are so small however that no definite conclusions can be drawn concerning these

Discussion As indicated above the functional end results in the present series are uniform and somewhat better in the age groups under 45 However the differences in relation to the age groups between 46 and 75 are not particularly marked The results for the latter age groups are similar to one another and these groups constitute the greater part of the series In view of this and the absence of any substantial differences in functional end results between the age groups it is concluded that *the importance of the age factor for the functional end result is slight*

12 Sex

There is general agreement in the literature that no sex differences can be demonstrated for functional end results after these fractures This was confirmed in Lidstrom s (1959) series

TABLE 23 *End results in relation to sex (follow up series)*

Result	♀		♂		Total no of cases
	No	%	No	%	
Excellent	82	24	23	28	105
Good	177	51	41	50	218
Fair	68	19	13	16	81
Poor	21	6	5	6	26
Total	348	100	82	100	430

Own cases The incidence of satisfactory results was somewhat higher in the male group compared with the female in the present series cf Table 23 This difference, however is not statistically significant Thus in this series too no difference between men and women can be determined in the functional end results after fracture of the distal radius

Discussion The agreement between the functional end results of the men and women in this series is somewhat surprising in view of the fact that the male group had a higher proportion of intra articular fractures which the present study ascribes a less favourable prognosis This is no doubt compensated however by almost half the men (40 of 82) in the series being between 16 and 45 years of age which is the range for which somewhat better end results were obtained

A 3 Type of fracture

In publications in which the degree of comminution and any intra articular involvement are included in the classification of the fractures it is just these factors that are reported to have a definite influence on the functional end result (Gartland & Werley 1951 Glock Mackel & Brown 1957 van Trappen 1964 Older Stabler & Cassebaum 1965) Lidström (1959) too found less satisfactory end results after comminuted fractures with joint involvement He did not consider on the other hand that the degree of primary dorsal dislocation was particularly relevant in this respect The fractures with primary volar dislocation did however present inferior functional end results A few authors (e g Ehalt 1935) have reported satisfactory results even for severely comminuted fractures that were treated in the same way as uncomminuted fractures There are also several authors who report that their special techniques for reduction and fixation have produced good results even after comminuted fractures (Gecheler 1953 Sikku 1953 de Palma 1952 Dowling & Sawyer 1961 Kane 1964 Sponsel 1964) It is occasionally reported that

cosmetic end results are less satisfactory after comminuted fractures with severe joint involvement but that the functional end results are nevertheless satisfactory (Kotrnetz & Geiringer, 1937)

Own cases The classification of the fractures in this series is based upon whether the fracture was extra articular or intra articular and also upon the degree of intra articular involvement Furthermore consideration was paid to the presence of fracture in the caput ulnae or the ulnar styloid process

Table 24 and Fig 25 give the functional end results in relation to type of fracture

It is clear that these results are better after the extra articular fractures than after the intra articular For the former there is no substantial difference between the fractures accompanied and unaccompanied by fracture in the distal ulna For the latter the results are also quite similar for the types of fracture unaccompanied by fracture of the distal ulna i e those types in which the primary displacement cannot have been particularly pronounced Among the three types of fracture accompanied by fracture of the distal ulna, the one in which the fracture was intra articular only in the radio carpal

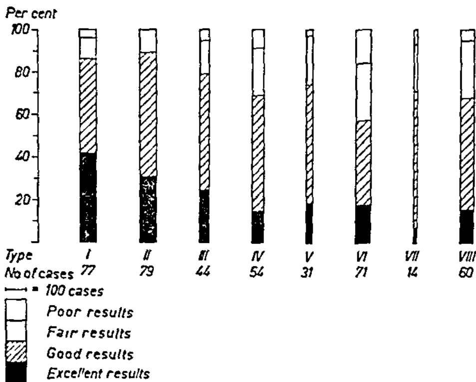


Fig 25 End results i relation to type of fracture

TABLE 24 *End results in relation to type of fracture (follow up series)*

Result	Type of fracture																Total no of cases
	I		II		III		IV		V		VI		VII		VIII		
	No	%	No	%	No	%	No	%	No	%	No	%	No	%	No	%	
Excellent	32	42	24	31	11	25	8	15	6	19	13	18	1	7	10	16	105
Good	34	44	46	58	24	54	29	54	17	55	28	39	9	64	31	52	218
Fair	8	10	9	11	7	16	12	22	7	23	19	27	3	22	16	27	81
Poor	3	4	—	—	2	5	5	9	1	3	11	16	1	7	3	5	26
Total	77	100	79	100	44	100	54	100	31	100	71	100	14	100	60	100	430

joint displays the best results The results are less satisfactory for involvement of both the radio carpal and the distal radio ulnar joints They are least satis factory however, for involvement of only the distal radio ulnar joint

Discussion It is not surprising that the extra articular fractures display better functional results than the intra articular since the latter always involve a risk of deformative changes in the joint surfaces and hence a dele terious effect on function It is somewhat remarkable that among the extra articular fractures there is no substantial difference in functional end results between cases with and without fracture in the distal ulna the presence of which implies a greater chance of displacement Among the intra articular fractures on the other hand the results are less satisfactory when the distal ulna is also involved Furthermore it is striking that among the intra articular fractures those with involvement of the distal radio ulnar joint plus fracture of the distal ulna have much less satisfactory end results than those in which the radio carpal joint is involved as well The only explanation afforded by *the present study is that it is just the fractures with involvement of the* distal radio ulnar joint that have a greater number of sequelae with functional impairment in this joint or injury to the median nerve

From the present results it may be concluded that *the type of fracture clearly influences the functional end results* which are less satisfactory after intra articular than after extra articular fractures In particular *involvement of the distal radio ulnar joint* seems to be *unfavourable for the prognosis* It is also clear that in intra articular fractures of the radius the addition of a fracture in the distal ulna leads to a deterioration of the functional end result

4 4 *Fracture of caput ulnae or ulnar styloid process*

Many authors report an incidence of 50–75% for fractures in the ulnar styloid process among fractures of the distal radius Although a large propor tion of the fractures in the ulnar styloid process do not heal most authors do not consider that this complication had an important effect on the end results in their series (Kahlevss 1897 Schinz 1922 Eskelund 1927 Grasby & Trick 1929 Cornell 1935 Bacorn & Kurtzke 1953 Lidstrom 1959) Others however report that this combination may prolong the period of treatment after fractures of the distal radius (Haglund 1914) and lead to instability in the distal radio ulnar joint with loss of function (Bange 1921) Ghormley & Mroz (1932) considered that fracture of the ulnar styloid process was often the cause of late complaints with tenderness They also divided their cases according to whether the ulnar styloid process was fractured or not Mac Au land (1937) has also reported that persistent symptoms were frequently due to tenderness over the ulnar styloid process though he ascribed this more

to incomplete healing in a ruptured ulnar collateral ligament than to poor healing of the ulnar styloid process

Similar opinions have been put forward by Reeves (1966) who operated upon a number of cases with persistent tenderness over the ulnar styloid process At operation he found not only a loose fragment from this process but also a radial displacement of the ulnar collateral ligament This in conjunction with the fragment, was assumed to result in painful locking in the ulnar *region of the wrist in* extreme dorsal extension volar flexion and ulnar deviation respectively After the fragment had been removed these patients pain di appeared

Smaill (1965) found that loss of mobility was more frequent after distal fractures of the radius accompanied by fracture of the ulnar styloid process than after distal radius fractures alone On the other hand his series did not have a higher frequency of pain in the former group

Discussion Opinions therefore differ as to whether fracture of the ulnar styloid process is of any prognostic importance whatsoever and also whether its presence causes persistent complaints I find Reeves' (1966) investigations most convincing in this respect The small number of cases in his study un*fortunately precludes any definite conclusions* No data *appear to have* been published about the importance of other fractures in the distal ulna

Own cases In the present *series* of 430 fractures of the distal radius 264 (61 4%) cases also had a fracture in the caput ulnae or the ulnar styloid process[1] The functional end results in these cases are compared with those in the cases without fracture in the distal ulna in Table 25

TABLE 25 *Comparison of end results in cases with and without fracture of ulnar styloid process u s p*

Result		With fracture of u s p		Without fracture of u s p	
		No	%	No	%
Excellent		55	20 8	50	30 1
Good		134	50 8	84	50 6
Fair		56	21 2	25	15 1
Poor		19	7 2	7	4 2
	Total	264	100	166	100

[1]) *A few cases in my series had fractures in both the caput ulnae and the ulnar styloid* process but most cases had a fracture in the latter only The former group is too small for an analysis of the end results in relation to those for the latter group In future therefore the expression "fracture of the ulnar styloid process" will be used synonymously with fracture of the distal ulna

The functional end results are clearly worse after fracture of the distal radius accompanied by fracture of the distal ulna There are thus 9 1% fewer cases with satisfactory results in this group

Discussion In view of this finding *the presence of a fracture in the distal ulna must be considered to affect the functional end results after fracture of the distal radius*

It may of course be difficult to specify exactly how this effect manifests itself It is conceivable however that fracture of the distal ulna may impair the function of the distal radio ulnar joint possibly though dysfunction in the disc and ligaments Of the 430 cases in the follow up series 80 had disturbances in the distal radio ulnar joint In no less than 67 of these 80 cases there was also a fracture in the distal ulna This aspect is discussed at greater length later on in this chapter

A 5 Anatomical end results (angulation and shortening)

The *relation* between the *anatomical* and the *functional* end results in fracture of the distal radius is widely discussed in the literature Several authors including Lidström (1959) regard this relationship as one of the central problems in the clinical management of this fracture As with many other factors in the clinical picture of distal radius fractures authors differ considerably in their opinions Three main attitudes can be distinguished

(1) *Deformity and impaired function are largely interdependent* This opinion is held by the majority In 1902 Rosenbach reported a series with unsatisfactory functional results in all cases of severe deformity in half those with moderate deformity and in only 11% of those without deformity Similar figures have been published by White (1940) Walker (1952) also found unsatisfactory function in one sixth of his cases without persistent deformity though in the rest of his series the degree of *deformity* clearly *affected* the functional result In contrast to these authors Taylor & Parsons (1938) assert that excellent anatomical results can always be expected to give satisfactory function in the wrist Other authors in this group consider generally without any reservations that a poor anatomical result has an unfavourable effect on the prognosis after fractures of the distal radius (Hitzrot & Murray 1921 Grasby & Trick 1929 Cornell 1935 MacAusland 1937 Mayer 1940 Hobart & Kraft 1941 Gartland & Werley 1951 Sirbu & Collof 1951 Glock Mackel & Brown 1957 Djorup 1962 Mandell 1965 Rehn 1965)

Lidström (1959) found that the functional end result was impaired by the degree of deformity but he also stated that even severe deformity does not usually impede a good functional result His series contained 27 cases with severe deformity of which no less than 14 had a satisfactory functional result

Published series of compensation cases also report a close connection between persistent symptoms and the degree of deformity after fracture of the distal radius Bacorn & Kurtzke (1953) for instance found that the degree of invalidity increased in direct proportion to the persistent, clinically demonstrable deformity

(2) *Only in special cases is the deformity of importance for function* Among the authors subscribing to this opinion Gurd (1937) considered that the deformity as such need not necessarily involve poor function of the wrist unless it is so pronounced as to include subluxation of the distal ulna According to Holund (1957) the functional end result is influenced by persistent deformity only in young and middle aged patients those over the age of 60 being unaffected in this way

(3) *The deformity has no or only limited importance as a contributory factor to poor functional results* Among the supporters of this view Bohler (1923) found that only axial displacement with radial shortening had an adverse effect on the cosmetic results the functional results being unaffected In Nissen Lie s (1939) series of fractures with primary displacement more than five sixths of the cases had incorrect anatomical relationships only a few of these cases with deformity had related clinical symptoms Like Pilcher (1917) and Cox & Meyer (1951) Lidstrom (1959) as mentioned above found that in a large number of cases with unsatisfactory anatomical results these did not impede a satisfactory functional result Cassebaum s (1950) series of 81 cases also showed largely excellent or good functional results in a number of cases in which the anatomical results were judged to be less satisfactory Similar opinions are expressed by Older Stabler & Cassebaum (1965)

Arbeitlang & Boeckl (1963) and Gambier & Venturini (1964) report that in their series the functional end result was not obviously influenced by the anatomical result since functional impairment appeared just as frequently among cases without deformity as in cases with severe deformity

Many authors also discuss which type of deformity is to be regarded as most detrimental to function Some including Grasby & Trick (1929) ascribe the poor functional result both to residual dorsal rotation of the distal radius fragment and to radial deviation of this with disalignment of the distal radio ulnar joint Edwards & Clayton (1929) found that dorsal angulation and radial deviation of the distal fragment are important but that a long interval elapsed before the radial deviation elicited symptoms in the distal radio ulnar joint

Several authors consider the most important deformity to be either shortening or radial deviation or a combination of the two frequently because they are accompanied by disturbances in the distal radio-ulnar joint (Rodgers 1944 Milch 1950 Hoffman 1953 Mason 1953 Guttman 1959 Milch 1963

1964) Milch (1950 1963 1964) in particular has stressed that shortening is the most important deformity If this is severe radial deviation develops followed ultimately by forward dislocation of the carpus with dorsal prominence of the caput ulnae This condition seriously impedes rotation in the distal radio ulnar joint leading to considerable functional impairment of the wrist Lidström (1959) also found that even a slight radial shortening as the only residual deformity increased the proportion of unsatisfactory functional results from 9% to 18% He did not consider dorsal angulation to be of much consequence for the functional result unless it amounted to more than 20° Above 21° however dorsal angulation caused a rapid deterioration of the functional results

A few authors (e g Poulsen 1906) report that radial deviation does not influence the functional end result

In some publications residual dorsal angulation is considered to be the most important cause of a poor functional result (Bankart 1929 E Madsen 1949 Gartland & Werley 1951 Wiklund & Mullern Aspegren 1956) E Madsen and Wiklund & Mullern Aspegren are of the opinion that more than 5° dorsal angulation is incompatible with a satisfactory functional end result while Hobart & Kraft (1941) found no detrimental influence up to 10° though a greater deformity than this impaired the wrist function As mentioned above Lidstrom (1959) did not find that the functional end result was affected by dorsal angulation up to 20

Own cases As pointed out already an x ray examination was not performed in all the cases in the present follow up series *after* the period of healing However the 224 out of 430 cases in which this was done have been shown to be representative for the total series The following comparison between anatomical and functional end results refers to this limited proportion of the total series

Table 26 and Fig 26 give the functional end results in relation to the degree of residual deformity as assessed in the manner described in Chapter VIII

Table 27 indicates the incidence of unsatisfactory (fair and poor) functional end results in relation to the two types of deformity (dorsal angulation and shortening) discussed in the review of the literature above

Discussion Table 26 suggests that the functional end result deteriorates with increasing deformity There are so few ca es of severe deformity that random factors may lie behind the apparently better results in this group It is neverthele s clear that severe deformity is not compatible with excellent results though it does not necessarily rule out a good result This remarkable circumstance has as mentioned been reported previously by Pilcher (1917) Cox & Meyer (1951) and Lidstrom (1959)

TABLE 26 *End results in relation to degree of residual deformity*
(2[illegible]4 cases in the X ray group)

Result	Degree of residual deformity								Total no of cases	
	None		Slight		Moderate		Severe			
	No	%	No	%	No	%	No	%	No	%
Excellent	[illegible]0	3[illegible]	18	19	2	3	0	—	40	18
Good	[illegible]	49	[illegible]1	54	30	48	7	64	116	[illegible]
Fair	6	11	2	[illegible]4	3	37	1	9	52	23
Poor	3	[illegible]	3	3	[illegible]	12	3	27	16	[illegible]
Total	57	100	94	100	6[illegible]	100	11	100	2[illegible]4	100

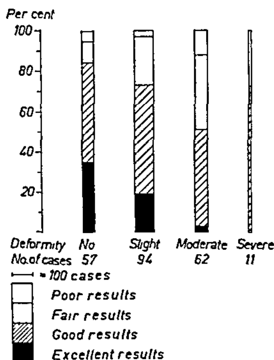


Fig 26 End results in relation to the degree of residual deformity

TABLE 27 *Incidence of fair and poor results in relation to dorsal angulation and shortening (224 cases in the X ray group)*

Shortening	Incidence of fair and poor results: No dorsal angulation	Slight dorsal angulation	Moderate dorsal angulation	Severe dorsal angulation
None	9/57 (=16%)	5/18 (=28%)	1/6 (=17%)	0/0 —
Slight	11/47 (=23%)	10/30 (=33%)	13/20 (=65%)	1/6 (=17%)
Moderate	6/15 (=40%)	4/7 (=57%)	5/13 (=38%)	1/1 (=100%)
Severe	0 0 —	1/2 (=50%)	0/0 —	1/2 (=50%)

From Table 27 it will be seen that the degree of dorsal angulation alone without any shortening only slightly increases the incidence of unsatisfactory functional end results

Table 27 also indicates that radial shortening as the sole residual deformity is a more regular source of a poor functional end result than is residual dorsal angulation by itself The detrimental effect of radial shortening does not become pronounced, however, until it is combined with a certain degree of dorsal angulation

With reference to the discussion above, it seems reasonable to conclude that *radial shortening was the deformity that exerted the greatest unfavourable influence on the functional end result*

From the results presented in Table 26 and Fig 26 it is clear that *a roentgenologically perfect anatomical result* arising from a satisfactory reduction and immobilization *cannot be taken as a definite guarantee of a satisfactory functional end result* The table also indicates that *not even severe deformity is a definite obstacle to satisfactory function* of the wrist after fracture of the distal radius

4 6 Interval between accident and follow up study

The length of the interval between the accident and the follow up examination is seldom considered in the literature as a possible influence on the functional end result

In a series of miners Magnus (1933) found that 30% had some invalidity when they returned to work at the end of treatment but that after five years the incidence was only 2½%

Lidstrom (1959) found in his series that unsatisfactory results were somewhat more common in the group followed up 2–4 years after the accident than in the groups examined less than 2 years and more than 4 years respectively after the accident However no definite tendency could be found towards a variation in the results with the length of this interval Hence it was concluded that within the limits concerned no significant effect existed

Arbeitlang & Boeckl (1963) report that in their series the number of cases with symptoms one year after the injury was almost four times as high as after three years Rehn (1965) found that the number of cases granted an annuity fell from 22 6% two years after the accident to 11% after four years

Own cases The follow up examinations in the present series were conducted between December 1960 and June 1961 The interval between the accident and the follow up examination ranged from one year two months to four years six months the mean interval being two years seven months

Table 28 and Fig 27 show the relation between the functional end result and the length of the interval between the accident and the follow up examination It will be seen that the functional result is somewhat better for the group having the longest interval between the accident and the examination The end results do not however vary a great deal between the different lengths of this interval It is perhaps most remarkable that the group with the longest interval does not have a single case with a poor functional end result This group is so small however that purely random factors may well have produced this result

Discussion In this context it should be noted that the cases in the present follow up series were treated during the period 15 October 1956 to 14 October 1959 An analysis by years shows that the different types of fracture are not distributed uniformly over the whole period As Table 29 shows there is a larger proportion of extra articular fractures among the early cases The difference seems to be offset by the next earliest group having a considerably smaller proportion of extra articular fractures in relation to intra articular fractures In the two most recent year groups the distribution between extra articular and intra articular fractures is much the same

The fact that extra articular fractures which have a more favourable prognosis make up a larger proportion of the year group likely to have the

TABLE 28 *End results in relation to the time between injury and follow up examination*

	Years								
	1 1/4–2		2–3		3–4		>4		Total no
Result	No	%	No	%	No	%	No	%	of cases
Excellent	29	26	38	21	31	28	7	28	105
Good	58	52	97	53	50	45	13	52	218
Fair	17	15	36	20	23	21	5	20	81
Poor	8	7	11	6	7	6	—	—	26
Total	112	100	182	100	111	100	25	100	430

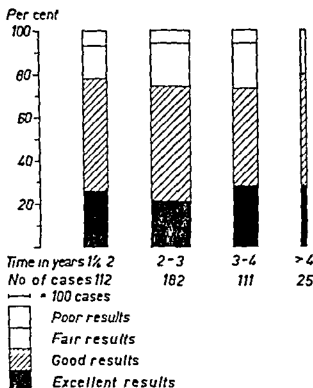


Fig 27 End results in relation to the interval between accident and follow up examination

longest interval between injury and follow up examination is probably one of the reasons why the functional results are better in the cases for which this interval is longest It therefore seems reasonable not to ascribe any practical importance to this finding and to draw the general conclusion that *the length of the interval between the injury and the follow up examination has no significant effect on the functional end results* in this series within the limits indicated above (This finding is also supported by the lack of significance for this factor in the statistical analysis)

TABLE 29 *Distribution of each year's cases by extra and intra-articular fractures*

Year of accident	Total	Extra articular	Intra articular
1956	21	47.6 %	52.4 %
1957	116	28.5 %	71.5 %
1958	1[illegible]8	38.6 %	61.4 %
1959	12	38.4 %	61.6 %

Review of the literature

Disturbances in the distal radio ulnar joint as a consequence of fracture of the radius have been extensively discussed in the literature Only Platt (1932) and Gartland & Werley (1951) consider that such disturbances are of little account

Opinions differ about the importance of the possible factors behind the disturbances Some authors place most emphasis on injury to the triangular disc or to other ligaments Others discuss various forms of malposition in the joint Only a few point to irregularities in the joint surfaces as a result of an intra articular fracture In view of these opinions and the unusual anatomical construction of this joint it seems suitable to make a distinction between three clinical types of injury to the distal radio ulnar joint (*a*) injuries to the ligamentous apparatus resulting in instability (*b*) disalignment in the distal radio ulnar joint and (c) changes in the articular surfaces with incongruity

(*a*) *Ligamentary injuries* The head of the ulna is connected with the radius by the interosseus membrane the distal radio ulnar articular capsule the triangular disc the ulnar collateral ligament the volar and dorsal radio ulnar ligaments the volar and dorsal radio carpal ligaments and the pronator quadratus muscle

Mitchell (1922) considered that the triangular disc is of primary importance for joint stability an observation that has subsequently been confirmed by Lippman (1937) and Lidstrom (1959) in autopsy specimens The latter authors found that *damage to the disc is essential for abnormal mobility of the caput ulnae but that the instability will be pronounced only if one of the radio ulnar ligaments is also ruptured* Milch (1942) considered that the essential stabilizing structure is the ulnar collateral ligament but this seems to be contradicted by the findings of Lidstrom (1959) and others

Instability of the joint was noticed already by Colles (1813) who found that the distal ulna was abnormally loose immediately after fracture of the distal radius Bange (1921) reported that instability of the joint often pre vented heavy work Mitchell (1922) on the other hand did not consider that abnormal mobility of the head of the ulna necessarily impairs function unless it is so great as to permit recurrent complete dislocation from the ulnar notch of the radius Lippmann s (1937) series had instability in the distal radio ulnar joint in every 9th case with a wide variety of symptoms that often included pain in the ulnar region of the wrist restricted supination and tenderness in extreme pronation Injury to the triangular disc with resultant laxity in the distal radio ulnar joint is considered by some authors to be of such prognostic importance that they use it as a criterion for the classification of these frac

tures (Taylor & Parsons 1938 Mayer, 1940 Manges Jr 1941) Lidström (1959) whose series included about 15% with laxity in the distal radio ulnar joint demonstrated that this complication has a detrimental effect on the functional end results after fracture of the distal radius

Instability in the distal radio ulnar joint involving recurrent complete dislocation of the distal ulna has been discussed by e g Mitchell (1922) Eldridge (1932) Henschen (1938) Hyman & Martin (1939) Birch Jensen (1951) and Bette (1957) In particular Eldridge Hyman & Martin and Bette agree in considering that such recurrent dislocation of the caput ulnae is a relatively common complication of distal fracture of the radius

Cochrane (1929) reported that residual volar dislocation of the caput ulnae is a common cause of poor end results after distal radius fractures Such a case has been published by Blaimont Buchin Geens & Kinnaert (1963) Edwards & Clayton (1929) assert that when the distal radius fractures the head of the ulna is dislocated volarly in relation to the radius fragment but that this is corrected as a rule when other components of the fracture are reduced

(b) *Disalignment in the distal radio ulnar joint* In a series of 400 normal cases Hulten (1928) found that physiological differences in the prominence of the caput ulnae lead to variations in the configuration of the distal radio ulnar joint The lengths of the radius and the ulna were the same in 61% of the cases while the ulna was 1 mm shorter in 15% 2 mm in 5 5% 3 mm in 2% and 4 mm in 0 3% the radius was 1 mm shorter in 10% 2 mm in 4% 3 mm in 1% 4 mm in 0 7% and 5 mm in 0 5% of the cases

Disalignment of the distal radio ulnar joint as a result of angulation or shortening of the fractured end of the radius has long been regarded as one of the causes of poor functional results after these fractures

Milch (1942 1950 1963) has investigated the causes of residual symptoms after fractures of the distal radius and found that the most important deformity is shortening which leads to radial deviation and ultimately to forward displacement of the carpus This gives rise to dorsal prominence of the caput ulnae and a relative lengthening of the ulna The displacement of the carpus causes the proximal row of carpal bones to impinge upon the ulna preventing rotation of the radius Milch distinguished roentgenologically between four types of axial malalignment (lineal transpositional, angulational and torsional) that may induce what he terms derangement about the wrist with symptoms in the form of prominence of the caput ulnae tenderness over the distal ulna weakness pain on motion and sometimes crepitus

Darrach (1913) noted that cases with loss of contiguity in the distal radio ulnar joint often present considerable pronation and supination defects He recommended resection of the caput ulnae in such cases Subsequently how

ever Darrach (1927) reported that patients had fewer complaints when a severe deformity of the distal radius was combined with a complete disruption of the distal radio ulnar joint than if the joint surfaces remained partly in contact This apparently correct and important observation has since been confirmed by for instance Raschle (1965) Shortening of the radius with partial dislocation of the distal radio ulnar joint is also discussed by Ehalt (1931) Hammond (1949) Cox & Meyer (1951) Hoffmann (1953) and Mason (1953)

In Lidstrom s (1959) series the cases in which shortening was combined with loss of contiguity of the distal radio ulnar joint had a 10–12% higher incidence of unsatisfactory end results than the cases of shortening without such loss of contiguity

Impaired forearm rotation is said to be a fairly common symptom in the above mentioned sequelae of distal radius fracture Schnek (1929) considered however that the restriction of pronation and supination was due to contracture and fibrosis of the pronator quadratus muscle while Patrick (1946) attributed the impaired rotation to obliteration of the joint space between the triangular disc and the caput ulnae as a result of scar formation after an injury to the joint capsule and the disc The disc could not slide smoothly over the head of the ulna hence the loss of rotation

(c) *Changes in the articular surfaces* Post traumatic changes in the joint surfaces due to intra articular fracture or arthritis in the distal radio ulnar joint have attracted relatively little interest Only a few publications give figures for the incidence of these two forms of articular disturbance

A number of authors including Lambrinudi (1938) and Albert Wohl & Rechtmann (1963) consider that arthritis in the distal radio ulnar joint is exceptional Lang (1942) pointed out that infractions in the ulnar notch of the radius are often overlooked and may lead to severe symptoms in the joint He also emphasized that roentgenological signs of arthritis in this joint appear a long time after the injury a point which he argued should be borne in mind when assessing patients with symptoms in this joint and a negative roentgenogram Chandler (1950) found that fractures which involved the distal radio ulnar joint generally gave rise to arthritis in this Grasby & Trick (1929) Watson Jones (1929) and Mason (1954) are the chief proponents of the view that arthritis in the distal radio ulnar joint is a common complication of fractures in this In Lidstrom s series only 5 of the 515 cases (less than 1%) were reported to have post traumatic arthritis in the distal radio ulnar joint The total incidence of arthritic changes in the wrist amounted to 5 7% Lidstrom considered that this figure did not permit any definite conclusions about the effect of this complication on the functional end results

Discussion The literature thus presents only sporadic attempts to distin

guish between lesions in the ulnar surface of the radius as a result of joint fracture on the one hand and secondary 'arthritis' on the other No one appears to have attached much importance to the fact that the incidence of intra articular fractures in the distal radio ulnar joint is as high as it is—a forgotten joint according to Guillermo (1938)

My findings, summarized on p 99 indicate that no less than 41% of the cases in the follow up series had intra articular fractures in the distal radio ulnar joint i e were liable to deformation of the radial surface of this joint This is emphasized by the results of the experimental fracture study (p 26) It was therefore particularly interesting to undertake the clinical examination described on p 53 as a means of 'isolating' symptoms from the distal radio ulnar joint

Own investigations

In the total follow up series of 430 cases 80 (18 6%) were found to have distinct pain on compression of the distal radio ulnar joint, as well as an accentuation of this pain upon compression during rotation It is notable that *all* these 80 cases had subjective symptoms from the injured region (Note that very few of the patients could themselves distinguish symptoms a cribable to the radio carpal or distal radio ulnar joints from those elsewhere in the carpal region)

Clinical findings As in the total series (see p 59) the most common symptom in this group was weakness in the hand and wrist (56 cases) This was followed by pain in the wrist on rotation (49 out of 80 cf 58 out of 430 in the total series) Since the presence of subjective symptoms was not considered compatible with an excellent functional end result in the present study none of the 80 cases could be classified under this heading

Table 30 indicates the inferiority of the functional end results in the 80 cases with symptoms from the distal radio ulnar joint compared with the

TABLE 30 *Comparison of end results in cases with and without disturbance of the distal radio ulnar joint (D R U J)*

Result	Cases with disturbance in D R U J %	Cases without disturbance in D R U J %
Excellent	—	30
Good	45	52
Fair	39	14
Poor	16	4

same results for the other 350 cases in the total follow up series In particular the incidence of unsatisfactory" results in the former group is more than twice as high as in the total follow up series (cf p 77) (The statistical analysis also shows that this complication has a highly significant influence on the functional end result)

The 80 cases with disturbance in the distal radio ulnar joint were subjected to the same clinical analysis as the total follow up series

Type of fracture Table 31 shows the distribution of the 80 cases by type of fracture and sex Compared with the corresponding table for the total series (Table 32) there is a still greater predominance of intra articular fractures in the present group Furthermore the majority of intra articular fractures in the 80 cases represent direct involvement of the distal radio ulnar joint

Laxity Only 9 of the 80 cases (11 2%) presented laxity in the distal radio ulnar joint which was thus only seldom important as an influence on the functional end result The low total incidence of laxity in my series (12 out of 430 cases in the total series 2 8%) is in striking contrast to the figure of 11 1% reported by Lippmann (1937) and Lidstrom s (1959) 14 9% There does not seem to be any direct explanation for this Perhaps it is nevertheless to be found in methodological differences

Both Lippmann and Lidstrom concluded that laxity in the distal radio ulnar joint had a deleterious effect on the functional end results in their series *In view of the results presented above the chief cause of the unsatisfactory* end results in these 80 cases must instead be considered to be primary or secondary deformation of joint surfaces or disalignment of the radius in relation to the ulna

There has been considerable discussion in the literature as to whether widening of the joint space as demonstrated in roentgenograms can be held to indicate instability in the radio ulnar joint Nowhere however is there any discussion of what is meant by joint space though it is clear that the term refers to the distance between the bone surfaces without allowing for the thickness of the cartilage The figures reported thus do not refer to the anatomical joint space To simplify comparisons the same principle was applied in the present series

Cornell (1935) reports that in his series of 156 cases of distal radius fractures 17% presented a diastasis in the radio ulnar joint Nothing however is said about the degree of instability in these cases In keeping with Lidstrom (1959) I question the value of this finding Lidstrom, with 77 cases of clinical instability in the distal radio ulnar joint found a radiological diastasis in only 18 i e 23 % On the other hand Marthaler (1959) considered that a widening of the joint space by more than 3 mm on the injured side was pathological In the present total series a final x ray examination had been performed on 10 of the 12 cases with instability in the distal radio ulnar joint Six of these ten had a widening of more than 3 mm in the distal radio ulnar joint space Little clinical importance should be attached to these figures Thus of the other 214 cases given

TABLE 31 *Type of fracture in cases with disturbance in the distal radio ulnar joint*

	Type of fracture																	
	I		II		III		IV		V		VI		VII		VIII		Total	
	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
No	3	—	5	1	5	1	2	2	8	1	21	4	5	—	18	4	67	13
%	3 8	—	6 25	1 25	6 25	1 25	2 5	2 5	10 0	1 25	26 2	5 0	6 25	—	22 5	5 0	83 7	16 3
Total No	3		6		6		4		9		25		5		22		80	
%	3 8		7 5		7 5		5 0		11 3		31 2		6 2		27 5			

Extra-articular = 11 3%

Intra articular = 88 7% (76 2% intra articular in distal radio ulnar joint or both joints)

TABLE 32 *Type of fracture in follow up series*

		Type of fracture																Total	
		I		II		III		IV		V		VI		VII		VIII			
		♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂
	No	63	14	68	11	26	19	42	12	23	9	63	8	11	3	5	8	319	82
	%	14 6	3 3	15 8	2 0	6 0	4 [illegible]	9 7	2 8	5 3	1 9	14 6	1 9	2 6	0 7	12 1	1 9	80 9	19 1
Total	No	77		79		44		54		31		71		14		60		430	
		17 9		18 4		10 2		12 6		7 2		16 [illegible]		3 3		14 0			

Extra articular = 36 3%

Intra articular = 63 7% (41 0% intra articular in distal radio ulnar joint or both joints)

a final x ray examination (i e those without instability in this joint) no less than 70 presented this degree of radiological widening The lack of convincing studies of the normal range in this respect is a further reason for attaching little importance to these findings

Radiological findings The analysis of changes in the distal radio ulnar joint would naturally have benefitted if the entire follow up series had been examined with the special roentgenological technique described on p 56 For various reasons however, this could not be done and the special x ray examination was performed in only 56 of the 80 cases (70%) with a disturbance in the distal radio-ulnar joint plus a control group of 69 cases from the other 350 (19 7%) in the series

Changes in joint surface In the group of 56 cases with symptoms in the distal radio ulnar joint the special roentgenological technique revealed changes in the joint surface in 42 (75%) A random sample from the control series matched by type of fracture displayed such changes in 18 out of 28 cases (64%)

It will be seen from Table 33 that among the cases with symptoms from this joint the incidence of changes in the joint surface is clearly higher for intra articular than for extra articular fractures There is admittedly a high incidence even among the extra articular fractures in the sample from the control group but this seems to be partly due to chance since a larger number of cases from the total control group displayed a lower incidence (40%) It therefore appears that the control group too in reality has a higher incidence of changes in the joint surfaces for intra articular compared to extra articular fractures

It is interesting that a special roentgenological examination is able to detect such a high percentage of changes in the joint surfaces even among cases in which the clinical examination failed to demonstrate any symptoms from the distal radio ulnar joint

TABLE 33 *Incidence of radiological changes in the distal radio ulnar joint (comparison between cases with and without clinical symptoms)*

		Cases with clinical symptoms		Cases without clinical symptoms	
		Extra articular	Intra articular	Extra-articular	Intra articular
Incidence of radiological changes	No	1/6	41/50	2/3	16/25
	%	16 7	82 0	66 7	64 0

The present examination has shown that there is a high significance of roentgenological changes in the distal radio ulnar joint in cases with clinical symptoms from this

The results indicate that post traumatic articular changes constitute one of the more important factors behind the genesis of clinical symptoms from this joint

The analysis also shows that roentgenologically demonstrable changes on the surfaces of the distal radio ulnar joint are present in as much as 64% of cases that do not have clinical symptoms from this joint However this analysis is based on only 28 cases and random factors may have been involved It is also possible that since the average length of the follow up period in these cases was only two years seven months many of these patients may develop clinical symptoms at a later date

Shortening and angulation In the total x ray series radial shortening was the deformity with the most frequent deleterious effect on the functional end result (see Table 27 p 92) The same analysis was performed for the 70 cases in the x ray series with clinical symptoms from the distal radio ulnar joint The findings presented in Table 34 show that when neither shortening nor angulation is present the end results are unsatisfactory in about 50% of the cases The degree of shortening does not seem to be important but the results tend to deteriorate somewhat with increasing dorsal angulation

However the individual groups are too small for any definite conclusions about the influence of these factors on the end results It is probable that other factors are more responsible for the poor results in these cases

Disalignment Lidström (1959) and others have asserted that radial shortening is related in no small degree to loss of contiguity of the distal radio ulnar joint as a result of distal displacement of the caput ulnae and that this had an adverse effect on the end result

TABLE 34 *Incidence of fair and poor results in relation to dorsal angulation and shortening (70 cases with disturbance in the distal radio ulnar joint in the X ray group)*

	Incidence of fair and poor results			
Shortening	No dorsal angulation	Slight dorsal angulation	Moderate dorsal angulation	Severe dorsal angulation
None	6/12 (=50%)	[illegible]/3 (= 6[illegible]%)	0/3 (= 0%)	0/0 —
Slight	5/16 (=31%)	8/11 (= 73%)	9/9 (=100%)	1/1 (=100%)
Moderate	2/4 (=50%)	3/3 (=100%)	3/3 (=100%)	1/1 (=100%)
Severe	0/0 —	1/2 (= 50%)	0/0 —	1/2 (= 50%)

In the 224 cases given a final x ray examination in my series special attention was paid to the degree of disalignment in the distal radio-ulnar joint in cases with shortening of the radius In 90 of the cases (40 2%) distal displacement of the caput ulnae amounted to more than 4 mm (cf the reference to Hulten 1928, on p 96 and Lindström 1959) These 90 cases (among the 224 given a final x ray examination) comprised 40 of the 70 (57 1%) with disturbance in the distal radio ulnar joint and 50 of the 154 (32 4%) without such disturbance The difference between these incidences indicates that disalignment in this joint is an important factor behind the disturbances noted

To test this line of reasoning the cases with "unsatisfactory results and shortening of the radius in the two series of 70 and 154 cases were classified according to the *presence of disalignment* in the distal radio ulnar joint and the degree of residual dorsal angulation The frequencies are compared in Tables 35 and 36

In the cases with clinical signs of injury in the distal radio ulnar joint the end results are an average of 10% worse for the group with disalignment in this joint whereas disalignment does not appear to have an unfavourable effect in the cases without clinical signs in this joint It is difficult to asse s

TABLE 35 *Incidence of unsatisfactory functional results in relation to disalignment in the radio ulnar joint in cases with shortening (70 cases with disturbance of the D P U joint in the X ray group)*

	Incidence of unsatisfactory results	
	No or slight dorsal angulation	Moderate or severe dorsal angulation
No disalignment	4/10 = 40 %	2/2 = 100 %
Disalignment	15/26 = 58 %	13/14 = 93 %

TABLE 36 *Incidence of unsatisfactory functional results in relation to disalignment in the radio ulnar joint in cases with shortening (154 cases without disturbance in the D.P U joint in the X ray group)*

	Incidence of unsatisfactory results	
	No or slight dorsal angulation	Moderate or severe dorsal angulation
No disalignment	9/38 = 23.7 %	0/3 = 0 %
Disalignment	4/27 = 14.8 %	6/23 = 26.1 %

the importance of residual dorsal angulation the variation in the results being probably due to the smallness of these groups For this reason and because it has already been shown that radial shortening apparently had the greatest deleterious effect on the functional end results in my series I considered it advisable to disregard the dorsal angulation in this and the following calculation

Disalignment also appears to be of great importance for the occurrence of articular changes in extra articular fractures of the distal radius Of the 48 extra articular fractures given a special roentgenological examination 13 out of 16 (81%) with distal displacement of the ulna had such changes whereas only 7 out of 32 (22%) had changes in the joint surface without distal displacement of the ulna

Tables 37 and 38 indicate the effect of shortening on the unsatisfactory end results in cases *without disalignment* in the distal radio ulnar joint Table 37 does the same for cases with functional disturbance in this joint and Table 38 for cases without such disturbance

The tables show a somewhat varied influence of shortening in both series It is clear however that *shortening has an unfavourable effect* on the functional

TABLE 37 *Incidence of unsatisfactory functional results in relation to shortening in cases without disalignment in the radio ulnar joint (0 cases with disturbance of the D R U joint in the X ray group)*

	Incidence of unsatisfactory results	
	No or slight dorsal angulation	Moderate or severe dorsal angulation
No shortening	8/15=53%	0/3= 0%
Slight moderate or severe shortening	4/10=40%	2/2=100%

TABLE 38 *Incidence of unsatisfactory functional results in relation to shortening in cases without disalignment in the radio ulnar joint (154 cases without disturbance in the D R U joint in the X ray group)*

	Incidence of unsatisfactory results	
	No or slight dorsal angulation	Moderate or severe dorsal angulation
No shortening	6/60=10%	1/3=33%
Slight moderate or severe shortening	9/38=23 7%	0/3= 0%

end result to about the same extent in both series (the "unsatisfactory" results in general are 15 6% and 10 8% more frequent in the presence of shortening)

In addition to changes in the joint surfaces this shows that *shortening with disalignment is an important factor relating to the inferior functional end results in these cases*

Relationship to other sequelae The 80 cases with injury and functional disturbance in the distal radio ulnar joint had a somewhat higher incidence of other sequelae compared with the total follow up series

Thus in the total series injury to the median or ulnar nerve was found in 11 cases (2 6%) of which no less than 5 (6 3%) belonged to the group with disturbance in the distal radio ulnar joint

Residual symptoms after a shoulder hand finger syndrome were found in five cases in the total follow up series Two of them only had remnants of organized oedema in the palm but no functional impairment both presented symptoms of disturbance in the distal radio ulnar joint The other three had shortening of the ligaments of the fingers with loss of finger mobility and varying degrees of functional impairment two of these also presented signs of disturbance in the distal radio ulnar joint

Discussion Functional disturbance in the distal radio ulnar joint was found in 18 6% of the cases in my series The importance of this for the functional end result has been shown to be statistically significant

The analysis of clinical data from the cases with disturbance in this joints strongly indicates that the symptoms were chiefly elicited by two factors *post traumatic changes in the joint surface* and *disproportion between the lengths* of the distal radius and ulna

In the present series *laxity* in the distal radio ulnar joint was so infrequent that its importance for the functional end result must be regarded as slight

The cases with disturbance in the distal radio ulnar joint also displayed a higher frequency of other complications after the radius fracture compared with the total series

The higher incidence of *neurological complications* may be ascribed to narrowing of the carpal tunnel due to swelling in the wrist It is not entirely clear whether the cases with disturbance in the distal radio ulnar joint had a greater tendency to swelling though it is worth noting that in one case (as well as in several outside this series), the compression of the nerve disappeared after subcapitular resection of the ulna

The higher frequency of a *shoulder hand finger syndrome* among cases with post traumatic disturbance in the distal radio ulnar joint is paralleled in other series (e g Lidstrom 1959) The tendency was clear in the present series even though there were very few cases with this complication

Review of the literature

Many authors report that nerve injuries are rare after fractures of the distal radius (Cotton 1900 Meyer 1925 Ghormley & Mroz 1932 Gurd 1937 Knapp 1952 Lidstrom 1959) In the opinion of certain authors (Turner 1924 Abbot & Saunders 1933 Sisefsky 1950) this is because both patient and surgeon concentrate chiefly on symptoms from the fracture with the result that any nerve injury is liable to be overlooked particularly as such injuries are usually partial and the symptoms disappear relatively quickly It is only seldom that any figures are reported for the incidence of nerve injury

Bacorn & Kurtzke (1953) found that in more than two thousand compensation cases the incidence of post traumatic neuritis was 0 2% Schlesinger & Leas (1959) report only one case of median nerve compression in 1000 fractures of the distal radius while Lynch & Lipscomb (1963) studying a ten year series of 600 cases from the Mayo Clinic found symptoms of median nerve compression in 3 3% It is worth mentioning that nerve injuries connected with distal fractures of the radius having been generally ignored in *the past are mentioned more frequently in modern textbooks on fractures* orthopaedic surgery and neurology e g by Haymaker & Woodhall (1953) and Moberg (1959)

Symptoms from the *median nerve* receive most attention in the literature no doubt because of this nerve s intimate relation to the distal radius and the clinical importance of median nerve injuries The first two cases were reported by Gensoul (1836) and Paget (1854) The former s case is particularly interesting as one of the few published instances of a primary median nerve injury in distal fracture of the radius Most authors have compiled reports on cases from the literature and added a few of their own (de Rouville 1905 Blecher 1908 Kirchheim 1910 Lewis & Miller 1922 Zachary 1945 Cannon & Love 1946 Newman 1948 Meadoff 1949 Love 1955 Blackberg & Fex 1956 Stein 1962 Bessot & Masse 1964 Manzotti 1964)

One of the more discussed surveys of median nerve injuries in fractures of the distal radius is that published by Abbot & Saunders (1933) comprising nine cases Their classification of these injuries which has since been adopted by several authors (e g Meadoff 1949 Lynch & Lipscomb 1963) distinguished between (1) Primary injuries (2) Secondary injuries (3) Late or delayed involvement and (4) Injuries associated with treatment in palmar flexion They were the first to point out the risk inherent in immobilization in pronounced palmar flexion and ulnar deviation (the Cotton Loder position *particularly common in* the United States) Their post mortem studies showed that when Berlin blue or lipiodol was injected between the layers of flexor

end result to about the same extent in both series (the 'unsatisfactory' results in general are 15 6% and 10 8% more frequent in the presence of shortening)

In addition to changes in the joint surfaces this shows that *shortening with disalignment is an important factor relating to the inferior functional end results in these cases*

Relationship to other sequelae The 80 cases with injury and functional disturbance in the distal radio ulnar joint had a somewhat higher incidence of other sequelae compared with the total follow up series

Thus in the total series, injury to the median or ulnar nerve was found in 11 cases (2 6%) of which no less than 5 (6 3%) belonged to the group with disturbance in the distal radio ulnar joint

Residual symptoms after a shoulder hand finger syndrome were found in five cases in the total follow up series Two of them only had remnants of organized oedema in the palm but no functional impairment both presented symptoms of disturbance in the distal radio ulnar joint The other three had shortening of the ligaments of the fingers with loss of finger mobility and varying degrees of functional impairment two of these also presented signs of disturbance in the distal radio ulnar joint

Discussion Functional disturbance in the distal radio ulnar joint was found in 18 6% of the cases in my series The importance of this for the functional end result has been shown to be statistically significant

The analysis of clinical data from the cases with disturbance in this joints strongly indicates that the symptoms were chiefly elicited by two factors, *post traumatic changes in the joint surface* and *disproportion between the lengths* of the distal radius and ulna

In the present series *laxity* in the distal radio ulnar joint was so infrequent that its importance for the functional end result must be regarded as slight

The cases with disturbance in the distal radio ulnar joint also displayed a higher frequency of other complications after the radius fracture compared with the total series

The higher incidence of *neurological complications* may be ascribed to narrowing of the carpal tunnel due to swelling in the wrist It is not entirely clear whether the cases with disturbance in the distal radio ulnar joint had a greater tendency to swelling though it is worth noting that in one case (as well as in several outside this series) the compression of the nerve disappeared after subcapitular resection of the ulna

The higher frequency of a *shoulder hand finger syndrome* among cases with post traumatic disturbance in the distal radio ulnar joint is paralleled in other series (e g Lidstrom 1959) The tendency was clear in the present series even though there were very few cases with this complication

the principles to be found in Sponsel & Palm's article (1965) These authors recommend expectant treatment in early cases and decompression surgery in late cases with healed fracture The least sign of thenar atrophy is considered an absolute indication for surgery in order to prevent further progress of the neurological symptoms The only difference of opinion concerning these principles concerns primary injury to the median nerve which according to e g Lynch & Lipscomb (1963) is caused by the nerve being pinched by the fracture fragment necessitating immediate surgery

It is remarkable that several very large series have no cases of injury to the median nerve (e g Bohler 1938 Nissen Lie 1939 Valtonen 1948 Wiklund & Mullern Aspegren 1956) This is certainly due to a lack of suitable examination techniques Compare the late discovery of the very common *"carpal tunnel syndrome"*!

Descriptions of injuries to the *ulnar nerve* in connection with fracture of the distal radius are less common in the literature compared with those to the median nerve Complications involving the ulnar nerve have been mentioned by Turner (1924) Cassebaum (1950) Djorup (1962) and Older Stabler & Cassebaum (1965) Neither these nor other authors who have dealt with corresponding problems provide any figures for the frequency of this complication Individual cases have been described by Lilienfeldt (1907) Cotton (1922) Lidstrom (1959) Britsch & Heller (1959) Lasserre (1963) and Hult (1964) Cotton (1922) emphasized that injury to the ulnar nerve after distal radius fracture is not so very rare particularly in the form of neuritis with loss of sensibility due to recurrent dislocation of the caput ulnae More recently Hult (1964) also argued that opinions about the rarity of ulnar nerve injury should be revised and pointed out that a correct diagnosis may be difficult in those cases in which only the motor branch of the nerve is injured and which therefore do not present radiating pain and numbness of the 4th and 5th fingers The case described by Lasserre (1963) with compression of the ulnar nerve fourteen years after a distal radius fracture had only loss of the motor function Lasserre's explanation was that the nerve had become caught between the deep fascia and the pronator quadratus muscle on one side and the head of the ulna on the other but that only the dorsal outer segment of the nerve (containing the motor fascicles) had been compressed While on this subject it is remarkable that Mumenthaler's (1961) extensive monograph on ulnar pareses does not consider injuries to the ulnar nerve in connection with distal radius fractures

Simultaneous injuries to the median and ulnar nerves after fracture of the distal radius have been reported in only two cases by Turner (1924) and Dickson (1926)

Own investigations

The work of developing special diagnostic methods for examining the sensibility of the hand has meant that neurological problems have been taken into account ever since the Department of Bone and Joint Surgery was set up at Sahlgrenska Sjukhuset It follows that the primary examination of the present series of distal radius fractures was carried out with such problems in mind

As reported in the chapter on investigation techniques all the patients in the series were asked at the follow up examination whether they had had any neurological symptoms in connection with or after their distal radius fracture The routine examination included functional tests of hand muscles innervated by the median and ulnar nerves The sensibility to pain and touch and the palpable sudomotor function were examined and recorded for the innervation fields of the median ulnar and radial nerves A ninhydrin test according to Moberg (1958) was made in all cases and served as an objective verification in most of the cases in which impaired sudomotor function was noted on palpation in connection with injury to the median or ulnar nerve In the cases displaying impaired nerve function the above routines were supplemented with tests of tactile gnosis using Moberg s (1958) picking up test and Weber s two point discrimination test

Of the 430 cases in the follow up series 14 (3 2%) had signs of nerve injury, i e impaired function of the median or ulnar nerve during the period of treatment or appearing later It is remarkable that no neurological symptoms had been observed in any of these cases at the time of the accident (see below)

The median nerve was affected most frequently—10 cases (2 3%) compared with 4 (0 9%) for the ulnar nerve There were no cases with simultaneous symptoms from both nerves

The most frequent subjective symptom from both nerves was numbness in the field of innervation This was reported at the follow up examination in eight of the median nerve cases and three of the ulnar nerve cases (see Tables 39 and 40 p 155) Only exceptionally did the numbness involve the *entire* sensible field the 2nd–4th fingers however were remarkably often involved in the median nerve cases Only one of these cases had the night time symptoms with early wakening from numbness in the fingers that frequently accompany compression of the median nerve from other causes Three of the patients with impaired sensibility suffered from clumsiness in the affected hand particularly in precision work with the thumb and forefinger In two other cases the loss of sensibility in the median field was accompanied by feelings of fatigue and weakness in the hand The latter symptoms were present without a loss of sensibility in another case Atrophy in the thenar muscles was noted at the examination in all these three cases

Various proposals for classifying nerve injuries connected with distal radius fractures were mentioned above in the review of the literature None of the cases in the present series can be described as primary i e with immediate symptoms Nor are there any in which the neurological symptoms can be directly related to the treatment given Consequently I have divided my cases simply into *early* and *late nerve injuries* In the *early* nerve injuries the symptoms appeared during the period of treatment between 14 and 47 days after the fracture of the radius in the *late* nerve injuries the symptoms did not appear until after treatment was complete the interval from the time of the fracture being at least three months (It should, however be mentioned that both before and after the present series there have been several cases at our clinic in which injury to the median nerve was observed immediately after the trauma In most of these cases, the symptoms disappeared spontaneously after a few months)

Since there were no cases in the present series in which injury was detected in both the median and the ulnar nerve the injuries to each nerve are considered separately in the following clinical analysis

Early injuries to the median nerve Six cases in the series (1 4%) were of this type Their clinical data are shown in Table 39 It will be seen that in two cases no objective signs of impaired function in the median nerve could be detected at the follow up examination although one of the patients reported residual numbness in all fingers of the injured hand (Both cases had clinical signs of disturbance in the distal radio ulnar joint which adversely affected the functional end result Resection of the ulna had been performed in case no 2 after which the objective signs of impaired median function had disappeared However this patient still had symptoms in the distal radio ulnar joint as well as a marked loss of strength which further contributed to a poor functional end result)

As will be seen from the table the other four cases had residual objective signs of injury to the median nerve Two of them presented loss of tactile gnosis as well as atrophy and disturbed function of the thenar muscles In none of these four cases could the result of the picking up test be regarded as pathological Nor however was the two point discrimination so impaired as to be incompatible with a normal picking up performance

Late injuries to the median nerve Four cases (0 9% of the total series) developed symptoms of disturbed function in the median nerve at least three months after the distal radius fracture (exact information about the time when the neurological symptoms appeared could not be obtained) All four cases displayed objective signs of impaired sensibility in the field of the median nerve as well as objective signs of loss of tactile gnosis The picking up test was definitely pathological in one case when undertaken blind the test could

be performed satisfactorily only with the aid of the thumb and little finger The normal picking up test in the other three cases can be explained in the same way as for the early cases The loss of sensibility in one of these four cases was combined with atrophy and disturbed function of the thenar muscles

As will be seen from Table 39, all ten cases with injury to the median nerve had intra articular fracture of the distal radius All the different types of intra articular fracture are represented, though with a preponderance of cases with such a fracture involving only the distal radio ulnar joint and accompanied by fracture of the distal ulna (type VI)

Intra articular involvement is the only etiological factor which these ten cases have in common as a possible contributory cause of the early and late appearance of dysfunction of the median nerve In the early cases intra articular haematoma and swelling are conditions that may have reduced the volume of the carpal tunnel In the late cases a similar reduction may have arisen through intra articular effusion and peri articular oedema as a result of post traumatic deformity in the radio carpal and, in particular the distal radio ulnar joints This is verified by the case in the series in which the objective signs of nerve injury disappeared after low resection of the ulna (see Table 39) (Similar cases outside the present follow up series have been observed at our clinic concerning the median as well as the ulnar nerve)

In half of both the early and the late cases of median nerve injury there were also compressive processes in the form of voluminous volar callus formation or volar projection of a bone fragment, sometimes combined with fairly marked residual dorsal angulation in the distal radius fracture This type of narrowing in the carpal tunnel is also likely to elicit symptoms of dysfunction of the median nerve

As mentioned above no importance was attached to the treatment of the fracture or more particularly the position of immobilization as a possible cause of the neurological symptoms in the present series None of the early cases had been immobilized in volar flexion, nor had any of the cases undergone repeated attempts at reduction

Early injuries to the ulnar nerve This group comprised two cases out of the total series of 430 (0 5%) Clinical data are given in Table 40

Late injuries to the ulnar nerve This group also comprised two cases (0 5%) and the clinical data will likewise be found in Table 40 As in the case of the late injuries to the median nerve the interval from the time of the fracture could only be determined approximately In one case the symptoms were judged to have appeared after more than three months in the other after more than four months

One of the cases (no 4) had had an open fracture of the distal radius and ulnar the skin being pierced on the ulnar volar surface of the wrist After

débridement and suture the wound had healed without complication In addition there was a comminuted fracture of the olecranon in the same arm Open reduction was performed on this At the follow up examination the patient had no symptoms from the injured elbow, in which the loss of extension and flexion amounted to only 20° In view of the good functional result after the elbow injury, the absence of subjective symptoms from the elbow and the lack of symptoms of injury to the ulnar nerve in the elbow region it seemed reasonable to classify this case as a late injury to the ulnar nerve due to the distal radius fracture

There is one extra articular and one intra articular fracture in both the early and the late group while each of these four cases with symptoms from the ulnar nerve belongs to a different type of fracture It is thus impossible to draw conclusions about any connection between type of fracture and type of nerve injury

Only the two cases with late symptoms from the ulnar nerve were given a final x ray examination One of them displayed a distal displacement of the caput ulnae by 5 mm with approximately the same shortening of the radius This case also presented signs of post traumatic disturbance in the *distal radio ulnar joint It is not clear whether these findings separately or* in combination contributed to the appearance of neurological symptoms In view of the intimate relation of the ulnar nerve to both the distal ulna and the distal radio ulnar joint the possibility of a causal connection cannot be *entirely ruled out In the other case with late symptoms from the ulnar nerve* the distal fracture of the radius and ulna had healed with about 20 radial deviation of both the distal radius and the distal ulna fragments In addition the proximal fragment of the ulna was displaced volarwards approximately 5 mm In this case it seems reasonable to conclude that this abnormal position after healing contributed to the occurrence of neurological symptoms since it must involve some continuous effect on the ulnar nerve

As with the injuries to the median nerve no connection could be established between the impaired function of the ulnar nerve and the treatment of the fracture (including the position of immobilization) in these cases

Discussion All the 14 cases with early or late symptoms of injury to the median or ulnar nerve were given the same routine treatment as the other fractures of the distal radius in this series A thorough neurological examination has been conducted on all fracture cases for many years now at this Department of Bone and Joint Surgery I am therefore convinced that no primary nerve injuries were overlooked in this series

For the same reasons it seems probable that the number of early nerve

injuries reported here also reflects the true incidence In view of the results from the examination the same seems to apply to the incidence of late cases

Of the conceivable etiological factors behind such nerve injuries in fractures of the distal radius (particularly injuries to the median nerve), it seems to me that the following deserve special consideration

1 In primary injuries a direct effect from the fracture fragment as illustrated in Fig 28

2 Primary intra articular or peri articular haematoma and swelling leading to a reduction in the volume of the carpal tunnel

3 Intra articular effusion and peri articular oedema as a result of disturbances in the distal radio ulnar joint similarly leading to a reduced volume of the carpal tunnel

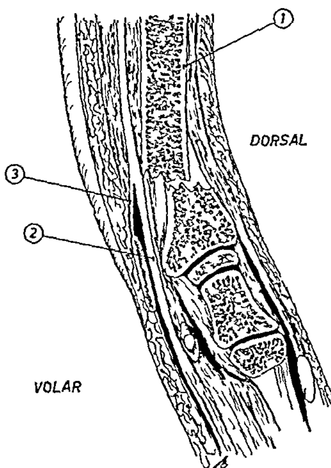


Fig 28 Fracture of the distal radius involving the median nerve 1 Radius 2 Median nerve 3 Palmar branch of median nerve

4 Voluminous callus formation or volar projection of a bone fragment again reducing the volume of the carpal tunnel

As shown in Tables 39 and 40 the functional end results in these cases of nerve injury are generally less satisfactory than in the total follow up series The neurological symptoms however were of decisive importance for the functional end result only in case no 7 among the median nerve patients—a 65 year old active businessman—and in case no 2 in the ulnar nerve group—a 75 year old active housewife with subjective weakness in the injured hand and considerable discomfort from a non sensible accident prone little finger

It has been suggested in the literature that a clear connection exists between a carpal tunnel syndrome after distal fracture of the radius and a shoulder hand finger syndrome or related conditions (Sponsel & Palm 1965) In this context and in the light of experience with cases outside the present series I feel it should be pointed out that a transient nerve injury is also liable to contribute to a shoulder hand finger syndrome even though this could not be demonstrated in the present series in which the incidence of this syndrome was so low

Conclusion The minor practical importance of the nerve injuries in the present cases *is no doubt explained by the relatively high age of these patients* at the time of the follow up examination They were thus relatively inactive with only moderate functional requirements This impression is supported by the fact that none of the patients accepted an offer of decompressive surgery

It should be added that *spontaneous regression* of the neurological symptoms can be expected in some cases when the swelling subsides This was observed in case no 9 in the median nerve group at a subsequent examination four years after the primary follow up

Experience at our clinic has shown however that there may also be a *secondary increase in incidence* particularly for injuries to the ulnar nerve as the deformation in the distal radio ulnar joint increases over the years This naturally applies chiefly to relatively young individuals

Concerning the therapeutic aspects of this complication to distal fractures of the radius I wish to emphasize the following

1 Primary appearance of neurological symptoms seldom calls for acute exposure of the nerve because the symptoms of nerve compression usually diminish upon reduction of the fracture and generally disappear soon after On the other hand the subsequent treatment of these cases is usually more difficult than in fractures of the distal radius without this complication and calls for more thorough supervision In particular prophylactic measures should be taken against a shoulder hand finger syndrome with intensive active exercises for both the shoulder and the finger joints in the injured arm

2 Persistent neurological symptoms and late cases call for decompression of the median nerve

3 In cases with symptoms of median or ulnar nerve injury and deformity in the distal radio ulnar joint the neurological symptoms may also disappear permanently after resection in the distal ulna

B 3 *Shoulder hand finger syndrome*

Review of the literature

This highly complex condition was first mentioned by Mitchell Morehouse & Keen (1864) As pointed out by e g Moberg (1951 1955) the syndrome has been given many different names which probably reflect the individual author s special interests in internal medicine neurology, rheumatology general surgery orthopaedic surgery, hand surgery or neurosurgery, though they may also indicate that different components or different stages in the development of the syndrome have been studied It seems that the most common terms in the French and Anglo Saxon literature are Dyplay s syndrome syndrome épaule main adhesive capsulitis painful stiff shoulder, frozen shoulder shoulder hand syndrome and post traumatic reflex dystrophy In the German literature one finds terms such as schmerzhafte Schulterversteifung and das Sudecksche Syndrom

This terminological confusion is understandable as such for several reasons Thus Codman (1934) referring to the shoulder component pointed out that this was difficult to define difficult to treat and difficult to explain from the point of view of pathology

Moberg (1955) considered that the literature available *at that time* suggested that this opinion applied not only to the shoulder component but to the syndrome as a whole He also observed that the complete syndrome is not often met with but that early stages of its various components are frequent Zachariae (1964) also considered it common and reported that the shoulder hand syndrome often starts with pain in the shoulder the changes in the hand being secondary to this She considered that a great deal was still unknown about the etiology and pathogenesis and that the syndrome had always been surrounded by a haze of mystery or the supernatural

It is therefore hardly surprising that, in the vast literature on this subject it is difficult to find a concise definition of this complex syndrome Moberg (1955) noted that it was an entity and an important problem in surgery of the upper extremity Wellmitz (1959) defined it as a neurovascular dysfunction through a hyperreactive state in the vegetative nervous system, which may be both exogenously acquired and endogenously inherited Zachariae (1964) found 'that certain patients may react in a special way to trauma

developing a state generally known as posttraumatic reflex dystrophy This is a serious complication frequently to an originally negligible lesion and at worst it may leave severe permanent sequelae

Regardless of the name adopted the syndrome is usually described as developing in three stages (de Takats & Miller 1943 Taylor 1958 Friedman Argyros & Steinbrocker 1959) as follows

1 A burning pain or a feeling of discomfort in the shoulder region develops after trauma to the upper extremity or during an internal disease Shortly afterwards sometimes with or before these symptoms pains and swelling appear in the hand and fingers The patient experiences pain on passive finger movements the skin folds are smoothed out and the patient is unable to flex the fingers Osteoporosis often occurs in the carpal and hand skeleton This first stage may last 3–6 months

2 The pain in the shoulder region disappears The swelling in the hand diminishes sometimes combined with increasing pain from finger movements and further loss of finger mobility In some cases there may be changes resembling Dupuytren s contracture There is usually a sensation of cold in the hand and some degree of dystrophic skin changes This stage may gradually develop into the third stage

3 Fibrosed deformed hand with contracted fingers (frozen hand) combined with frozen shoulder The pains in the hand and shoulder have disappeared and the affected extremity presents a state of severe invalidity

It is said that this progress may be arrested at any stage either spontaneously or as a result of treatment The second stage like the first is reported to last 3–6 months whereas the third develops very individually with irreversible changes and contractures and may persist for years A typical feature is said to be that the elbow joint is never affected

Moberg (1951) appears to have coined the term *shoulder hand finger syndrome* for this condition In subsequent reports on its clinical and therapeutic aspects (1955 1960 1963) he states that it comprises two components—a shoulder component and a hand finger component—of which only one is generally present in the early stages subsequently perhaps becoming the dominant clinical manifestation of the syndrome The two components are closely interrelated *representing the main links in the sequential chain that* gives the syndrome its character of a vicious circle

As mentioned above Zachariae (1964) found that in spite of the extensive literature produced on the etiology and pathogenesis of the syndrome these aspects were by no means exhaustively investigated In this context I must limit myself to quoting from the major works to indicate the two main pathogenetic principles that seem to have emerged

The *etiological factor* is said to vary from not infrequently very minor trau

matic conditions in the upper extremity to internal diseases such as cardiac infarction, rheumatoid arthritis or paretic states due to cerebral injury Mental and psychological factors have also been considered as a background to the syndrome largely in an attempt to explain why, among patients with identical injuries only some develop the syndrome Wellmitz (1959), for instance asserted that both dispositional and constitutional factors were involved Zachariae (1964) referring to patients given a psychiatric examination before being operated upon for Dupuytren s contracture also reported 'It is obvious then that the patient s mental status prior to the operation influences the development of postoperative dystrophy Although these mental factors are probably not the sole explanation, they no doubt constitute an important detail in the syndrome

Although Steinbrocker & Argyros (1958) found that it was usually anxious hypersensitive patients who contracted the syndrome they did not consider psychological factors were important for its genesis They added however, that psychogenic factors may play a major part in maintaining and aggravating the condition Moberg (1960) expresses much the same opinion Obviously, the attitude of the patient to his disability plays an important role in all of these mechanisms The active patient is not able to keep his damaged arm strictly immobilized even if he attempts to do so Therefore the function of the pumping system is retained On the other hand the passive patient, especially the hypersensitive one will immobilize himself completely even following slight trauma '

From the *pathogenic aspect* as already mentioned the literature seems to distinguish between two main principles

According to one of these the shoulder hand finger syndrome is caused by disturbances elicited reflexly via the autonomic nervous system As early an author as Sudeck (1900 1901) proposed that the osseous atrophy described by him depended upon trophoneurotic disturbances, a theory which he based on the assumption of a dominant neurogenic factor This theory has since been suported by several authors (Leriche & Fontaine 1930 de Takats 1937 Haldbo 1942 de Takats & Miller 1943 Miller & Miller 1951 Bertelsen 1958 Steinbrocker & Argyros 1958 Friedman Argyros & Steinbrocker 1959 Mayfield & Newquist 1959 Wellmitz 1959 Thompson, 1961 Weissenbach 1964) These authors conception is that pain from a peripheral focus is transmitted on afferent pathways to spinal centres from which the impulses travel via internuncial pools (described by Lorento de No 1938) to the efferent sympathetic pathways The importance of the cells described as internuncial pools has been particularly emphasized by Steinbrocker Spitzer & Friedman (1948) and Thompson (1961) They comprise a diffuse network of interconnected neurones in the grey matter of the spinal medulla Through them impulses can

be dispersed to lateral and anterior parts of the spinal cord as well as to different segments of this Thompson considers that this may in fact explain why the shoulder hand finger syndrome has such a complex symptomatology and why it sometimes occurs bilaterally Mayfield & Newquist (1959) found further support for this autonomic neurogenic factor in the pathogenesis in the experimental finding that prolonged bombardment of extremital regions in both animals and man with painful stimuli elicited oedema in the tissues

The other main theory concerning pathogenesis is based on quite different physiological phenomena Earlier authors such as L Bohler (1923) probably came close to this pathogenic factor with their theories but it is not until fairly recently that its physiological background has been elucidated by Moberg (1951 1955 1960) whose opinions have subsequently been supported by e g Zukschwerdt (1962) and Beasley (1964) Moberg found that the central feature in the pathogenesis of the shoulder hand finger syndrome is an impairment of the pumping mechanism in the arm The efficiency of the arterial supply depends upon the blood pressure whereas on the venous side the pressure is low and the transport of blood and lymph away from the extremity requires external factors such as active muscle function in the arm and active function of the hand Since the anatomical relationships are such that the pumping mechanism in the arm is most efficient at the shoulder and in the dorsal metacarpal region it follows that functional disturbances in the shoulder region and the hand—separately or in combination—may seriously impair the backflow of the venous and lymphatic systems The efficiency of the pumping mechanism in the shoulder is upset by immobilization of the shoulder joint A similar deleterious effect on the pumping mechanism of the shoulder joint is produced by immobilization of the arm through the use of a sling or by the immobility of bed ridden patients The oedema in the hand appears first in the dorsal region later in the palm and fingers as well It prevents normal movements of the hand and fingers finger flexion being affected first The patient is no longer able to clench the fist completely and the efficiency of the pumping mechanism in the hand is also impaired In conjunction with the disturbance in the shoulder mechanism this increases the oedema in the hand resulting in a vicious circle This chain of events may be reversed i e injury to the hand or paralysis of this as a result of injury to central or peripheral neurones impairs the pumping mechanism of the hand resulting in oedema in this The resultant defective function of the hand may then—particularly in inactive or elderly individuals—lead to impaired function of the arm and hence to contracture in the shoulder region

According to Moberg the shoulder hand finger syndrome is an entity a vicious circle in which the chief links are the shoulder component and the hand finger component The shoulder component is perhaps less liable to

manifest itself clearly The pathophysiological core of the syndrome however is the disturbed circulation arising from the defective pumping mechanism and the most deleterious consequence of this—the hand oedema In Moberg s opinion it is also the hand oedema which determines the long term prognosis in this syndrome Oedema that has lasted for any time always leaves some thing behind Some will always be converted into diffuse cobweb—like scar tissue Most of this tissue is formed in the subcutis particularly immediately peripheral to the fascia but some will be found in all the tissues The greater the oedema and the longer it persists the more scar tissue is formed Severe oedema leaves a hand with atrophic skin stiff joints and a poor grasp sometimes resembling a rake Two forms of deformity may develop In the more common variety the metacarpophalangeal joints stiffen in extension and the interphalangeal in flexion (intrinsic minus hand) In the other variety, the interphalangeal joints stiffen in extension while the metacarpophalang geal joints retain a slight power of flexion (intrinsic plus hand) Which of the two deformities results is dependent on the strength of the long flexors and extensors compared to that of the short muscles of the hand (intrinsic muscles) '

Moberg holds that the disturbance to the pumping mechanism outlined above is quite sufficient to explain the genesis of the shoulder hand finger syndrome and that consequently there is no reason to trace it to some un explainable factor Concerning the possible involvement of the sympathetic nervous system, Moberg considers that disturbances in this are definitely present in the cases of true causalgia associated with multiple lesions of peripheral nerves the chief characteristic of which is hyperalgesia Such cases however are usually ones of war wounds with multiple lacerations and—unlike the shoulder hand finger syndrome—generally involve younger persons In these cases the disturbance in the sympathetic nervous system soon inter mingles with symptoms of a defective venous backflow Summing up on the shoulder hand finger syndrome Moberg writes In injuries of every day life it is difficult to determine whether or not a mild form of reaction from the sympathetic nervous system is included in the shoulder hand finger syndrome

The *treatment* recommended for the syndrome in the literature largely reflects the individual author s conception of the pathogenesis If the auto nomic nervous system is held to be chiefly responsible blockade of the stellate ganglion sympathectomy or ganglionectomy is recommended usually to gether with both passive and active exercises 'Antiinflammatory' therapy with corticosteroids and phenylbutazone derivatives is also said to be effective Supporters of the other pathogenic principle rely mainly on restoration of the pumping mechanism of the hand and arm the chief aid being a systematic utilization of the patient s ability to perform *active* movements It is also

considered essential to avoid using slings unnecessarily large plaster bandages and splints i e devices which impede or prevent movement

Irrespective of the pathogenic principle followed and the attendant treatment recommended it seems to be generally agreed that the prognosis in cases with a shoulder hand finger syndrome entirely depends on early diagnosis and early treatment

The occurrence of the shoulder hand finger syndrome and allied conditions *in connection with distal fractures of the radius* has been recognised for many decades now von Lesser (1887) reported finding trophic disturbances in musculature and hand after typical fractures of the radius leading to considerable loss of function in the hand Le Breton (1915) published 10 cases that seem to have presented a typical shoulder hand finger syndrome though he describes them as arthritis of the joints of the hand following Colle s fracture" Four of these cases resulted in some degree of permanent invalidity Hansen (1926) presenting a series of compensation cases considered that in not a few instances dystrophy was the cause of functional disturbances with stiff finger and hand joints after ideal reduction of distal radius fractures Pickard (1927) regarded the stiff hand as the most deleterious residual symptom of such fractures usually caused by faulty immobilization treatment and held that the post traumatic syndrome on a neurovascular basis was rare Kotrnetz & Geiringer s (1937) series included a small number of severe and a larger number of mild circulatory disturbances after distal radius fractures both types being particularly frequent in the fractures treated with primary reduction They consequently recommended reduction to be postponed until at least 24 hours after the accident de Takats & Miller (1943) had only one case of Colles fracture in their series of 33 cases with post traumatic dystrophy In Rosen s (1947) series of 280 distal fractures of the radius no less than 10 cases had post traumatic dystrophy with swelling oedema pains and loss of mobility Of the four cases with posttraumatic reflex dystrophy presented by Miller & Miller (1950) two had a fracture in the distal end of the radius Cassebaum (1950) discussed the shoulder hand finger syndrome as a possible complication of distal radius fractures and recommended prophylaxis in the form of active finger and shoulder exercises Knapp (1952) discussed two conditions as complications of distal radius fracture one of which he termed post traumatic fibrosis and the other Sudeck s acute post traumatic atrophy of bone The first he ascribed to post traumatic oedema the second to reflex sympathetic dystrophy Since both conditions were due to diminished activity Knapp strongly emphasized the importance of maintaining the activity of normal function throughout the period of healing by convincing the patient that the injured hand could and should be used for normal daily functions In their large series of more than two thousand

compensation cases of distal radius fracture Bacorn & Kurtzke (1953) found causalgia in 0 1% and 'Sudeck's atrophy also in 0 1% changes resembling Dupuytren's contracture were present in 0 2% and loss of shoulder mobility in 1% If one assumes that these indefinite manifestations in fact represent one and the same condition namely the shoulder hand finger syndrome, the frequency of this in their series would be 1 4% Hoffman (1953) reported that his series of 35 cases of dislocated distal radius fractures included no less than 10 with clinical symptoms of Sudeck s atrophy during the post traumatic period Two of these cases presented a poor functional result two years after the injury Lidström s (1959) series of 515 cases of distal radius fractures included 53 (10 3%) in which the post traumatic course had been complicated or prolonged by post traumatic causalgia' by which Lidström does not mean 'true causalgia The functional end results were unsatisfactory in 67% of this group, a much worse result than for the rest of the series Lidstrom notes that repeated attempts at reduction had not contributed to the poorer results in this group Discussing the incidence of Sudeck s syndrome' after distal fractures of the radius Bartsch & Heller (1959) note that Bohler had an incidence of only 0 33‰ but add that differences in this respect probably reflect the manner of interpreting the clinical picture They had not found a single case of true Sudeck' in a series of 365 cases of distal radius fractures from the Bohler Clinic, a result which they attributed to the Clinic s consistent application of certain therapeutic principles The most important of these principles in the present context were said to be (1) Local anesthesia without delay in order to prevent all unnecessary pain, (2) Split the plaster bandage immediately after reduction (3) Exercises at once and (4) Frequent controls for the first few days after the accident

In Djorup's (1962) series of compensation cases the 39 patients with at least 10% invalidity after the distal radius fracture included as many as 10 (over 25%) in which the invalidity was occasioned by 'reflex dystrophy' In the series of Raschle (1965) and Rehn (1965) the incidence of Sudeck s atrophy lay between 6 5% and 8 5% They stated that this was one of the most severe complications after distal fractures of the radius Rehn in particular warned against an *excessively* short period of immobilization massage and passive exercise i e factors which he considered liable to promote the development of the syndrome

Discussion I have not found any mention in the literature of series of distal radius fractures in which a consistent attempt has been made to prevent this complication or treat it early with measures aimed at a supposed *neurogenic* factor The effect of such therapy when introduced at a late stage is of course extremely limited

It thus seems that no studies of radius fractures have been published which

provide a relatively exact picture of the pathogenesis of the complication referred to here as the *shoulder hand finger syndrome*

As in the case of the distal radius fractures themselves however causal relationships can be studied—as indicated by the incidence data reported above—by collecting sufficiently large series of *similar* cases A comparison in this respect seems to be feasible between my series and other large ones in the literature

Own investigations

It seemed important to investigate whether a disturbed lymphatic and venous circulation (Moberg 1951) can be shown to be the essential pathogenetic factor behind the shoulder hand finger syndrome Since my series was treated consistently according to the principles outlined on p 51 and since no measures were taken specifically to counteract any neurogenic pathogenetic factor I find the series suitable for the type of study indicated above

Some points should be mentioned before proceeding to the clinical data of the cases with shoulder hand finger syndrome

It is possible that the ages in these cases differ from those in other published series since exact data in this respect are not generally provided for the latter As pointed out below however a typical feature of the syndrome is said to be that it does not generally occur in patients below the age of 40 while it is most frequent above the age of 50 It is also said to be more common among women

Some idea of the exactness of the reduction and the quality of the immobilization in my series can be derived from the information about whether reduction was attempted repeatedly Repeated attempts are often cited as a possible etiological factor but the incompleteness of data about this in the literature renders a comparison with my series impossible

My follow up series of 430 cases was found to include 9 (2 1%) in which the shoulder hand finger syndrome had been present during treatment Only one of these developed the changes associated in the literature with Sudeck s syndrome

It is worth noting that six of the nine patients were women i e 1 8% of all the women in the series while the three men comprised 3 6% of all the men This runs counter to the general conception that the syndrome is more frequent among women but the discrepancy in my series may of course be of an occasional nature

The main clinical data on these nine cases have been compiled in Table 41 p 155 In particular I wish to note the following

1 None of the patients with this complication was younger than 40 while only two were below the age of 55

2 Most of the patients (six) displayed little personal activity during the period of treatment while three seemed to be emotionally unstable and sensitive individuals At the follow up examination these three cases (nos 2, 3 and 7) displayed clear residual symptoms of a shoulder hand finger syndrome

3 Two of these patients (nos 2 and 3) had a disturbance in the distal radio ulnar joint

4 Seven of the nine cases had intra articular types of fracture this is a still larger proportion than in the total follow up series (63 7%) The intra articular fractures in the total follow up series displayed a greater tendency to primary dislocation compared with the extra articular group and hence reduction was indicated more frequently (cf Table 49 p 134) In the present group of nine cases all the intra articular and one of the extra articular cases had the fracture reduced, while *in half of these the reduction had to be repeated* This is a marked discrepancy from the total follow up series in which reduction had to be repeated in only 12 of 295 cases (4%)

5 The symptom was detected less than 20 days after the accident and the primary treatment in only two cases neither of which called for repeated reduction of the fracture Both the shoulder and the hand finger components of the syndrome were present in five cases of which four had undergone a repeated attempt at reduction (cf above) Only the hand finger component was manifest in the other four cases two of which were those where the syndrome appeared early during treatment

6 None of the nine cases had any injury to the affected arm apart from the distal fracture of the radius A sling was never used to immobilize the arm In fact the patients were all instructed from the start to perform active exercises in both the shoulder and the finger joints In four of the nine cases (nos 3 6 7 and 8) it was soon evident that the patient could not be relied on to perform the active exercises which were consequently supervised by a physiotherapist three of these patients (nos 6 7 and 8) being hospitalized for this reason

7 *Brief hand status in cases 2 3 and 7 Case no 2* Flexion defect in metacarpophalangeal joints II–V on maximal clenching the finger tips came to within 1½ cm of the proximal palmar fold extension defect of 10–20° in the proximal interphalangeal joints of fingers II–IV *Case no 3* Slight flexion defect in metacarpophalangeal joints II–V on maximal clenching all the finger tips reached the palm 1 cm proximal of the proximal palmar fold extension defect of 10–15° in proximal interphalangeal joints of fingers II–IV but distal interphalangeal joints normal *Case no 7* Slight flexion defect in metacarpophalangeal joints II–V on maximal clenching the distances from the finger tips to the proximal palmar fold were 1½ 2 2 and 1½ cm extension defect of 10–15° in proximal interphalangeal joints of fingers II–V This

was the *only* case in the series in which an x ray examination (about three months after the accident) revealed changes resembling Sudeck s osseous atrophy

Discussion At the follow up examination only three of the nine cases (0 7% of the total series) had such a degree of residual functional loss after the shoulder hand finger syndrome that their functional end result was affected In two other cases (0 5% of the total series) traces of the syndrome were detected at the follow up examination but did not influence the functional end result

In eight of the nine cases in which the shoulder hand finger syndrome was present during treatment the syndrome most probably contributed to a prolonged total incapacity for work

All these eight cases had had the fracture reduced and in half of them the reduction was repeated

None of the patients with the shoulder hand finger syndrome displayed signs of any vegetative disturbances or any multiple lesions of peripheral nerves with causalgia as a symptom

All the patients were over 40 years of age at the time of the accident

The majority were markedly inactive and three were also emotionally unstable In my opinion these two factors were undoubtedly important for the development of the syndrome in these cases In the other cases no endogenous factors could be associated with the appearance of the syndrome

The findings from the follow up examination indicate that the chief cause of residual changes after the shoulder hand finger syndrome was the finger hand component of this

The total incidence of the shoulder hand finger syndrome in my series of distal radius fractures (2 1%) is remarkably low compared with other published series even though the nine cases undoubtedly include some relatively slight instances of the syndrome There are still fewer cases with residual functional loss from the syndrome (3=0 7%) and the degree of this loss is also slight My series also has a strikingly low incidence of cases corresponding to Sudeck s osseous atrophy (1=0 2%)

The only factors which distinguish my series from those most comparable to it in the literature are as follows

1 A sling was never used for immobilization of the arm after fracture of the distal radius

2 Active exercise of both the shoulder and the finger joints in the injured arm was always instituted at once and carefully supervised

3 In cases in which the shoulder hand finger syndrome developed the patient s actives exercises were very carefully supervised most of these patients were consequently hospitalized for the intensified active therapy

TABLE 12 *Lesion of the extensor pollicis longus tendon*

Identification	Type and side of fracture	Reduction	X-ray before reduction (∧)	X-ray after the end of treatment (∧)	Length of immobilisation (days)	Onset of symptoms (days after injury)	Reconstruction	Other complication	Length of follow up (months)	Functional end result	Remarks
1) ♀ 60 years	II Right	+	Dorsally dislocated fragment 10 dorsal 10 radial	10 dorsal 10 radial	18	62	—	—	50	Fair	Grip strength impaired Loss of mobility
2) ♀ 82 years	VIII Right	+	15 dorsal *0 radial*	30 dorsal *0 radial*	28	28	+	Disturbance of D R U	25	Fair	Grip strength impaired Tendon function good, but unable to raise the thumb over metacarpal plane
3) ♀ 73 years	II Left	—	15 dorsal 5 radial	Not done	No plaster (1st examination 3 weeks after injury)	90	—	—	29	Fair	Pinching grip impaired

+ = Yes
— = No
D R U = Distal radio ulnar joint

Conclusion The most important conclusion from this investigation is that the incidence of the shoulder hand finger syndrome could be kept very low compared with most other published series *simply by instituting measures to promote the circulation right from the start*

As far as can be judged this follow up series does not differ from other similar series in respect of severity of the fractures age of the patients or other factors that might influence the incidence of complications Pathogenetically therefore the circulation factor described above (Moberg) has been found to be decisive for the occurrence of the syndrome—a finding which to my knowledge has not been demonstrated before

B 4 *Rupture of the extensor pollicis longus tendon*

Ever since Heineke (1913) first published a case of subcutaneous rupture of the extensor pollicis longus tendon as a complication of a distal radius fracture this tendon lesion has received a great deal of attention in the literature Thus recent compilers in this field (Strandell 1955 Mendelaar 1960) report that out of all such tendon ruptures to be found in the available literature some 80% were complications of fractures in the distal radius The part played by the radius fracture in this context is the subject of considerable controversy although most authors state that the complication occurs most frequently in such fractures without dislocation (Lipschutz 1935 Aronson 1939 Bjorkroth 1941 Trevor 1950 Strandell 1955 Witter 1960 Carlberg Delmotte Stehman & van Gaver 1961)

Own investigations

My series of 430 fractures of the distal radius—with rupture of the extensor pollicis longus tendon in three cases (0 7%)—is not an adequate basis for an analysis of either the pathogenesis or the therapy in this complication I shall therefore simply note that the incidence of this complication which is interesting in many respects agrees with corresponding data This is a further indication that my series is fully comparable with those published earlier

None of my three cases with this complication displayed any marked dislocation in the fracture at the primary roentgenological examination In this respect too there is thus good agreement with current opinion

Concerning pathogenesis and therapy I refer for the reasons given above to the studies by Strandell (1955) Davidsson (1956) and Bache (1959)

Table 42 gives the clinical data for the three cases in my series with subcutaneous rupture of the extensor pollicis longus tendon as a complication to distal fracture of the radius

It may be mentioned here that in the statistical analysis of the total follow up series by means of multiple regression analysis (cf Chapter XII) this factor was found to be of some significance for the end result after the fractures of the distal radius in my series As already pointed out however the number of cases is so small that this finding must be interpreted with the utmost caution

CHAPTER XII

STATISTICS

The statistical analysis of the numerical data involved testing hypotheses concerning correlations between functional end results Y and one or several of the following variables X_i (1) age (2) sex (3) type of fracture, (4) fracture of ulnar styloid process U S P (5) dorsal angulation (6) shortening and (7) interval between injury and follow up examination

Processing of the data was formally facilitated by expressing the qualitative variables in numerical terms (e g for sex men=1 women=2) This was also done for the variable type of fracture the different types being arranged in an ascending order according to the primary assessment of their severity

It seemed reasonable to regard the functional end result as a purely linear function of the variables X_i

$$Y = \alpha + \Sigma\beta_i X_i$$

This implies that one ignores all interactions which appears biologically reasonable

Under these conditions the analysis of the correlations—in principle a multiple analysis of variance—can be undertaken in the form of a multiple regression analysis

Since the statistical investigation was set up as a test of hypotheses the estimates of the regression coefficients β_i were not calculated

The hypotheses were tested in the form

$$t(\nu) = \frac{\hat{\beta}}{S_{\beta}} \quad \nu = d\ f$$

where β is an estimate of β and S_{β} is the estimated standard deviation of the estimation

If $t(\nu) = t_{95}(\nu)$ the hypothesis that a correlation exists between a variable X_i and the functional end result Y is accepted

Owing to a lack of uniformity in the data, they had to be divided into two groups A and B Complete data on all the variables were available for the individuals in group A while in group B data were lacking on the variables

'dorsal angulation and shortening', i e those which could not be registered until after the final roentgen examination

A comparison of groups A and B with respect to their composition by sex age and type of fracture did not reveal any significant differences and consequently they have been treated as random samples from the same population with respect to the variables studied

An analysis was first made of the correlation between the functional end results and the factors X_i that were common to groups A and B The results have been compiled in Table 43 together with the partial regression coefficients making it possible to grade the strength of the correlation

It will be seen that 'type of fracture and 'age are significantly correlated with the functional end result, whereas the other variables cannot be shown to influence the end result

As already mentioned the variables dorsal angulation' and 'shortening' had to be excluded from this analysis which concerned all the individuals in the follow up series In order to test the hypothesis concerning the influence of these variables on the functional end result a multiple regression analysis was performed on group A with the functional end result Y as the dependent variable and age type of fracture, dorsal angulation and shortening as independent variables The results are shown in Table 44

It will be seen that shortening too, is significantly correlated with the end result (owing to the smaller number of individuals the significant correlation between age and functional end result in the total follow up series cannot be demonstrated in this group)

Thus *the statistical analysis demonstrates* that

(1) The functional end result deteriorates with increasing age of the patient

(2) The functional end result deteriorates with the severity of the type of fracture

(3) Shortening involves a deterioration of the functional end result

TABLE 43 *Functional end result as a function of age sex type of fracture U.S P (fracture of the ulnar styloid process) and interval*

$n = 430$

Factor	Regr coeff	S_β	t	Part corr coeff
Age	0 0095	0 0029	3 20*	0 17
Sex	0 0839	0 1076	0 77	0 04
Type of fracture	0 0765	0 0176	4 34*	0 23
U S P	0 0484	0 0870	0 54	0 13
Interval	0 0036	0 0040	0 91	0 04

TABLE 44 *Functional end result as a function of age type of fracture dorsal angulation and shortening*

$n = $ [illegible]

Factor	Regr coeff	S_{β}	t	Part corr coeff
Age	−0 0009	0 00[illegible]8	−0 [illegible]	0 09
Type of fracture	0 08[illegible]5	0 0[illegible]10	3 9[illegible]	0 31
Dorsal angulation	0 1005	0 0606	1 66	0 24
Shortening	0 2[illegible]62	0 0713	3 [illegible]9*	0 31

As for the other factors the above analysis has left the question of their influence on the end result open All that can be said is that *the present data do not support any hypotheses that these factors influence the functional end result*

Another analysis analogous to the above was undertaken concerning the correlations between various sequelae and functional end result (Table 45) In order to isolate these relationships, an analysis was also made of group *A* in which the effects of age type of fracture and shortening could be eliminated The results are shown in Table 46 with the significant factors marked with an asterisk

TABLE 45 *Correlations between functional end result and sequelae total follow up series*

Sequela	Part corr coeff	T value
Symptoms from distal radio ulnar joint	0 38	5 76*
Injury of median or ulnar nerve	0 [illegible]0	4 46*
Shoulder hand finger syndrome	0 [illegible]6	3 97*
Injury to tendon of extensor pollicis longus	0 08	2 13*

TABLE 46 *Correlations between functional end result and sequela X ray series*

Sequela	Part corr coeff	T value
Symptoms from distal radio ulnar joint	0 49	6 30
Injury of median or ulnar nerve	0 18	3 03*
Shoulder hand finger syndrome	0 34	3 97*
Injury to tendon of extensor pollicis longus	0 0[illegible]	1 63 not sign

In order to test the value of the significant correlations reported above, an attempt was made to use the regression functions calculated in the first two analyses as predictors of the functional end result In this procedure each individual s score for age type of fracture etc is inserted in the re gression function to produce a figure which should correspond to the functional end result achieved The calculated figures are rounded of to the nearest whole number since the variable 'functional end result is expressed in whole numbers

In the total follow up series 47% of the results were correctly predicted, in group *A* 53% These figures should be judged in relation to entirely ran dom predictions which turn up correct for about 25% of the results in both cases

CHAPTER XIII

CLINICAL ASPECTS OF END RESULTS IN CERTAIN TYPES OF CASES

This chapter contains brief descriptions of some clinical aspects of the end results in certain types of cases referred to in passing elsewhere in this thesis These cases are grouped under four headings namely (a) Fractures with volar displacement (b) Fissure fractures (c) A comparison between reduced and unreduced fractures and (d) Fractures with open reduction

Fractures with volar displacement

My series included 17 cases of fractures with volar dislocation Their distribution by sex age and type of fracture has been reported in Chapter V on p 40 where it is noted that compared with the total follow up series men and the young age groups are over represented in these cases

Table 47 gives the functional end results for these fractures with volar dislocation There is no statistically significant difference between these results and those for the total follow up series (cf p 77) and consequently this group is reported together with the latter

Fissure fractures

In Chapter V (p 39) it was noted that the 10 fissure fractures in my series included a much smaller proportion of intra articular fractures compared with the total follow up series and that the number of fissure cases in the youngest age groups was disproportionately high

TABLE 47 *End results of fractures with volar displacement*

Result		♀		♂		Total	
		No	%	No	%	No	%
Excellent		3	30	1	14	4	23 5
Good		4	40	4	57	8	47
Fair		2	20	2	29	4	23 5
Poor		1	10	—	—	1	6
	Total	10	100	7	100	17	100

It was found in the follow up series that the functional end results are better for extra articular types of fracture and better too in the young age groups It is therefore not surprising that as shown by Table 48, the functional end results for the 19 cases with fissure fractures are considerably better than those for the total follow up series

An unsatisfactory functional end result was displayed in two of these nineteen cases In both cases it was due to subjective symptoms and objective findings of a loss of strength

Since not all the cases of fissure fracture had satisfactory end results I did not feel justified in excluding them from the follow up series

TABLE 48 *End results of fissure fractures*

Result		♀		♂		Total	
		No	%	No	%	No	%
Excellent		6	43	5	100	11	58
Good		6	43	—	—	6	32
Fair		1	7	—	—	1	5
Poor		1	7	—	—	1	5
	Total	14	100	5	100	19	100

A comparison between reduced and unreduced fractures

Table 49 shows the reduced and unreduced cases in my series by type of fracture

TABLE 49 *Type of fracture (reduced and un reduced cases)*

Type of fracture		Reduced		Un reduced	
		No	%	No	%
I		29	37 7	48	6[illegible] 3
II		58	73 4	21	26 6
III		19	43 2	25	56 8
IV		39	72 2	15	27 8
V		19	61 3	12	38 7
VI		63	88 7	8	11 3
VII		12	85 7	2	14 3
VIII		56	93 3	4	6 7
	Total	295	68 6	135	31 4

It will be seen that the number of reduced cases predominates in the groups in which the radius fracture is combined with a fracture in the distal ulna This seems natural in view of the greater tendency to dislocation that is presumably displayed by these types of fracture Fracture types V and VII however are exceptions in this respect Here it seems that reduction was indicated more frequently by involvement of the distal radio ulnar joint with malposition in this

An attempt was made to compare the end results in reduced and unreduced fracture cases for the different types of fracture Many of the groups in such a comparison were so small that random factors could not be excluded and consequently it was impossible to draw any definite conclusions from the results As a single group however the reduced cases had somewhat inferior results compared with the unreduced cases (satisfactory results in 71 9% and 82 3% respectively) This does not of course imply that the reductions were responsible for the inferiority of the results The true explanation is simply that the reduced and the unreduced fractures largely correspond respectively to those with primary dislocation and those without The current opinion in the literature is that end results are adversely affected by primary dislocation Consequently my series does not differ appreciably in this respect from those published previously

Fractures with open reduction

My series includes seven cases of open reduction performed in each case after primary closed reduction In five cases the result of the latter had proved unsatisfactory while the other two had early re dislocation in spite of optimal immobilization

Table 50 gives the distribution of these cases of open reduction by age sex and type of fracture It will be seen that the cases concerned six men in the younger age groups and only one woman (62 years) The fracture was intra articular in all cases with considerable displacement of the joint surface Malposition of articular fragments was thus the indication for the open re duction in all these cases Four of the fractures displayed volar dislocation

In five cases the fracture fragment was fixed with intraosseous steel wire loops in the other two with subcutaneous Kirschner wires These measures gave a satisfactory position of the articular fragment and there was no further dislocation

Table 51 gives the functional end results in these cases Unfortunately a roentgenologically and clinically comparable series of un operated cases is not available against which to evaluate the surgical treatment in these cases Their end results are inferior to those for the total follow up series but this

Chapter VI gives an account of the treatment employed in the follow up cases The only respects in which my series deviates from current principles are that slings and passive traction were prohibited active shoulder and finger exercises being instituted immediately instead These changes markedly reduced the incidence of the shoulder hand finger syndrome (possibly synonymous with Sudeck s atrophy) in my series besides leading to a much reduced need for physiotherapy

Chapter VII describes the examination techniques employed in the follow up study When collecting anamnestic data particular attention was paid to the possible presence of neurological symptoms The clinical examination was conducted along pre determined lines and included an assessment of the appearance of the wrist the degree of impaired mobility and loss of strength A special technique was used to test the function of the distal radio ulnar joint A neurological examination of the injured hand including a ninhydrin test was undertaken in every case Cases with signs of dysfunction of the median or ulnar nerves were further tested for tactile gnosis with the two point discrimination test and the picking up test

A final roentgenological assessment was possible for a limited part of the series (224 cases) which proved to be representative for the total follow up series Residual angulation and shortening were measured from the roentgenograms A special roentgenological technique employed in 125 of the 224 cases permitted a more exact assessment of any changes in the articular surfaces of the distal radio ulnar joint

Chapter VIII presents the results of the follow up examination Subjective symptoms were reported in 52 3% of the cases the most frequent complaint being weakness in the hand and wrist

The *anatomical end result* assessed on the basis of the degree of angulation and shortening determined roentgenologically was classified as excellent in 25% of the series whereas 38% had an excellent *cosmetic end result* denoting the degree of radial deviation and prominence of the caput ulnae This discrepancy is a reflection of the circumstance that even a relatively marked skeletal deformity does not always affect the outward appearance of the wrist

Some degree of *impaired mobility in the wrist* was observed in as many as 77% of the cases being more frequent in those types of distal radius fractures that were combined with a fracture of the distal ulna In most cases the loss of mobility had not been noticed by the patient

Only three cases in the follow up series had a *loss of finger mobility* this was a residual symptom after a shoulder hand finger syndrome in all three cases

A *loss of strength* in the injured hand was found in 24% of the cases the leading hand being particularly prone in this respect A functional disturbance

in the distal radio ulnar joint seemed to increase the incidence of loss of strength as did an intra articular compared with an extra articular fracture Most of the patients had themselves noticed the loss of strength

The series included 11 cases with *neurological disturbances* The median nerve was affected in eight cases the ulnar nerve in three All eleven cases also had subjective neurological symptoms

In three cases there was *injury to the extensor pollicis longus tendon*

Signs of *injury to the distal radio ulnar joint* were detected in 80 cases (18 6%) all of which had various kinds of subjective symptoms

The techniques reported here can thus objectively locate a considerable proportion of the symptoms directly to the distal radio ulnar joint These symptoms not infrequently dominate the individual case In this way it has been shown that a fair number of cases can be ascribed to a group that will respond to treatment I intend to return to this question in a future publication

Chapter IX reports the criteria for an evaluation of the end results based upon the findings from the follow up study Previous systems are discussed particularly that used by Lidstrom (1959) which after certain modifications was also employed for assessing the end results in my series (see p 75) The results are thus assessed from an evaluation of subjective symptoms as well as objective findings Compared with Lidstrom however I have paid more attention to the presence of impaired loss of mobility and loss of strength

The functional end results are classified under four headings excellent good fair and *poor*

Chapter X contains a discussion of the functional end results in my series These were Excellent 105 cases (24%) Good 218 cases (51%) Fair 81 cases (19%) Poor 26 cases (6%)

It is pointed out that even though the proportion of poor functional results in my series is not particularly large the well known frequency of distal radius fractures means that a large number of individuals annually are liable to *suffer permanent disability as a result of this injury*

Chapter IX is concerned with the clinical analysis of my series Factors are considered which may be particularly relevant for the functional end result A distinction is made between general factors (age sex type of fracture fracture of the distal ulna anatomical end result i e angulation and shortening and the interval between the accident and the follow up examination) and special factors" (injuries to the distal radio ulnar joint nerve injuries shoulder hand finger syndrome and rupture of the extensor pollicis longus tendon)

The clinical analysis of the influence of these factors on the functional end result produced the following findings

(1) Type of fracture is correlated with the end result which is worse for intra articular than for extra articular fractures The prognosis is particularly adversely affected by involvement of the distal radio ulnar joint in the fracture

(2) A simultaneous fracture in the distal ulna involves some deterioration in the functional end results of distal radius fractures

(3) Of the two forms of roentgenologically determined deformity in the radius shortening seems to have a more deleterious effect than angulation on the *functional end result*

(4) The age factor shows only a very weak correlation with the functional end results

(5) Neither the sex factor nor the interval in the present series between *the accident and the follow up examination appear to have any demonstrable* effect on the end results

(6) Injury to the distal radio ulnar joint (including an intra articular fracture here) leads to a deterioration in the functional end result

(7) Residual conditions after a shoulder hand finger syndrome and unoperated rupture of the extensor pollicis longus tendon involve an impaired functional end result

(8) The functional end results were unsatisfactory in the cases with nerve lesions in my series These lesions appear to be a contributory factor but there were only two cases out of eleven in which the nerve lesion was solely responsible for the poor end result

Interactions naturally exist between these factors The validity of the conclusions from the clinical analysis was further tested by means of a statistical analysis of the individual factors

Chapter XII presents the results from this statistical analysis which took the form of a multiple regression analysis This showed that of the ' general factors age type of fracture and shortening had a significant effect on the functional end results whereas sex fracture of the distal ulna angulation and the interval between the accident and the follow up examination did not significantly affect the end results

Of the special factors injuries to the distal radio ulnar joint nerve injuries and shoulder hand finger syndrome were shown by the statistical analysis to have a significant effect on the end result

Chapter XIII briefly reviews certain clinical aspects of the end results for the groups of cases having *fractures with volar displacement fissure fractures,* and *fractures with open reduction* together with *a comparison between the reduced and unreduced fractures* No good reason was found for considering these groups of cases separately in other parts of this thesis

General conclusion

Distal radius fractures can be reproduced in biomechanical experiments provided the wrist is arranged within certain limits of dorsal or volar flexion

The fracture s intra articular involvement particularly in the distal radio ulnar joint is of considerable importance and elicits both subjective and objective late symptoms from this joint in a large proportion of cases The diagnosis of disturbance in the distal radio ulnar joint makes it possible to introduce adequate therapy

Shortening of the radius also has a considerable adverse effect on the end result Here too a disturbance in the distal radio ulnar joint appears to dominate the symptoms

Nerve lesions after fractures of the distal radius are not particularly common but when present their effect is considerable

The shoulder hand finger syndrome—which leads to very poor end results when not treated adequately—can be prevented and treated with active exercises and by avoiding the use of immobilization with a sling This strongly indicates that the shoulder hand finger syndrome is a sign of circulatory insufficiency a theory which had previously been assumed but not to my knowledge proved

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SUPPLEMENTUM 109

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To our wives

Table of Contents

Preface

The present study on structural changes in the cervical spine started in 1964 and was completed two years later During 1967 the collection of information was brought together and the report to follow written The authors want to thank particularly dr Erland Lysell and dr Yngve Olsson for most valuable assistance during different phases of this project, mrs Inga-Lisa Elzer and miss Lena Johnsson for skilfull technical work and mrs Birgitta Pande for secretarial help

During 1965 and 1966 dr Jorge Galante held a research scholarship from the International College of Surgeons permitting him to stay in Goteborg Professor Fritz Schajowicz made several research visits to this institution to participate and activate the completion of this investigation It received its final shape at a country place on the Swedish east coast during an unforgettable peaceful summer vacation made possible by affectionate understanding of our wives

The study was supported by the following institutions and foundations, The Swedish Medical Research Council, The Swedish Labour Market Insurance Society, Fylgia Insurance Society and EIR Insurance Society

Herrang, Sweden
July, 1967

Introduction

Disturbances in the cervical spine causing restriction of motion, neck stiffness and referred pain either through the upper extremities, the head, the face or through the chest are extremely common According to Hult (1954) approximately 70% of the Swedish population suffer from this condition once or repeatedly

The onset of the symptoms is mostly in middle age but it is not uncommon even in young adults Although the prognosis is in general good for the majority of cases treated conservatively there has been a growing tendency during the last decades to attempt surgical procedures in the severely afflicted

The symptoms have been related to different patho anatomical lesions of various components of the cervical spine Narrowing of the intervertebral foramen caused by osteo arthritis of the apophysial joints, osteophyte formation of the unco-vertebral region, degenerative changes in the discs with or without posterior herniations and abnormal motion in vertebral segments have been the principal patho anatomical lesions implicated

These conditions have been thought responsible for the involvement of the neural and/or of the vascular elements in the foramen which are in close relationship to the posterior and lateral parts of the vertebral components

Different diagnostic methods have been introduced to elucidate the type and site of the underlying mechanism There is often a lack of correlation between the clinical and radiographic picture Symptoms and signs of degenerative lesions of the cervical spine may be present in the absence of radiological findings on plain films, while gross radiological changes may be

present in patients in the absence of symptoms In view of this, other roentgenological methods such as laminography, cineradiography, discography, myelography, intraosseous vertebral venography and vertebral artery angiography have been employed in order to extend the visualization of the lesions But in spite of these extensive diagnostic techniques the correlation between the clinical picture and the pathological lesion is still uncertain (Hirsch 1960, Hirsch, Wickbom, Lidstrom and Rosengren 1964)

Clinical radiographic procedures visualizing structural changes in the cervical spine (Hirsch Wickbom et al 1964)

A Plain X rays
B Discography
C Myelography
D Venography



Fig 1 A AP lateral and oblique plain X rays of a female patient of 52 illustrating a narrowed disc between C.VI and C.VII and osteophytes protruding into the corresponding intervertebral foramen

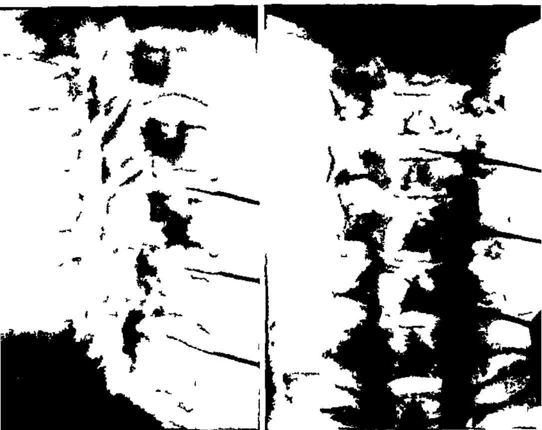


Fig 1 B Female patient of 48 On plain films the C V—C VII levels look normal Needles have been introduced under television X ray control in order to perform discograms at C V C VI and C VII disc levels Water soluble radio paque contrast has been injected into C VI and C VII but not yet into C V The contrast has leaked mainly postero laterally bulging into the spinal canal and the intervertebral foramen through the uncus region



Fig 1 C Male patient of 51 Pantopaque myelogram illustrating indentations at C VI—C VII and to a less degree at C V—C VI

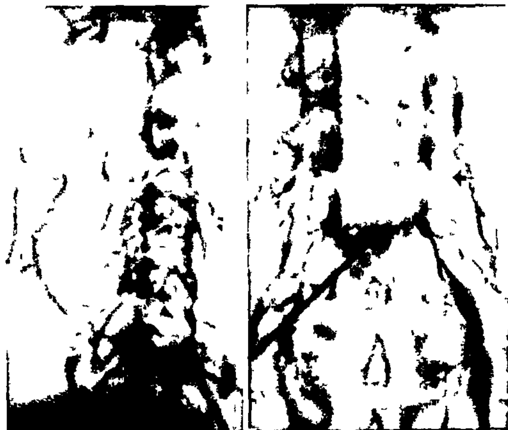


Fig 1 D Venography after injection of contrast material in the C VI vertebral body On the left side the filling of the venous plexus is interrupted at the C V—C VI level (arrow) illustrating the fibrous tissue elements causing the indentations on the myelogram in Fig C affecting both the root sleeves and the veins which are lying anatomically very close in the foramen

As the main clinical complaint is pain sometimes accompanied by other neurological disturbances great attention has been given to methods indicating involvement of nerve elements mainly by electro-diagnostic means, especially electro-myography Since symptoms can be relieved by local anaesthesia, para-vertebral ganglion blocks have been tried to determine the site of the lesion All the above-mentioned methods have their obvious clinical limitations

The lack of basic knowledge of cervical spine physiology, anatomy and pathology and a clear understanding of the etiology of the clinical symptoms has led to many different surgical procedures in order to decrease or eliminate the possible causal factors In principle two lines have been adopted 1 Decompression of nerve and vascular elements at the foramen by laminectomy, hemifacetectomy, resection of osteophytes and protruding disc material 2 Fusion of vertebral bodies with or without removal of degenerated discs to eliminate motion and abnormal mechanical influences upon nerve structures The result of these surgical procedures have not always been satisfactory This has resulted in a great controversy with respect to the efficacy of the different procedures

There is to-day a growing tendency to accumulate more information about the normal and morbid conditions of the cervical spine in order to be able to evaluate the significance of the different structural changes and their clinical importance With this in mind it was felt that a comparative morphological study covering different age groups would help to clarify some features of possible clinical importance still under discussion

Survey of Literature

During the last decades a growing number of papers and several monographs have been published regarding the cervical spine (Ecklin 1960, Jackson 1965, Hall 1965, Brain—Wilkinson 1967) Both the normal and morbid anatomy still seem to be subject for discussion

According to Bowden (1966) the nucleus lies closer to the back than to the front of the disc However, it is Jackson's (1965) opinion that the nucleus is placed slightly anterior to the centre of the disc and that the annulus is thicker posteriorly than ventrally

Tondury (1959 and earlier) and Ecklin (1960) found degenerative changes in the disc starting in the unco-vertebral region at the age of 20 years The changes are more conspicuous and the number of levels increases with age The levels of C V —C VI and C VI—C VII according to Payne and Spillane (1957) have the highest frequency of disc involvement

Osteo-arthritis of the apophysial joints is more common in the mid-cervical and upper cervical regions (Holt and Yates 1966) According to Friedenberg et al (1959) and Payne and Spillane (1957) there seems to be no correlation between the changes in the apophysial joints and the discs These joints frequently escape involvement even when the disc shows marked degeneration, and severe degeneration of apophysial joints could occur in the presence of normal discs Degenerative changes especially spur formation in discs and/or joints may make the vertebral foramen narrower and reduce its size to 1/4 with flattening and destruction of the nerve (Hadley 1944)

Nerve root lesions are frequently associated with disc degeneration and apophysial joint arthritis Holt and Yates (1966) found cysts in the posterior nerve roots where they join the dorsal root ganglion The frequency varied from none in the second and third root to more than 10 % in the sixth Frykholm (1951) found root sleeve fibrosis causing constriction and angulation of the nerve roots The root sleeve fibrosis is usually secondary to chronic compression of the radicular nerve

Roentgenographic studies by Hadley (1944) which included oblique views and tomograms with good demonstration of the intervertebral foramen and adjacent areas, indicated that degenerative changes in discs are not sufficiently demonstrated by this technique Morton (1950) found that fissuring of the discs, posterior herniation and posterior protrusions of the annulus could not be identified roentgenologically Lipping and eburnation of the vertebral bodies, thinning and ossification of the discs and osteo-arthritis were visible The correlation between roentgenographic and anatomical findings regarding the disc degeneration was 67% but it was poor concerning changes in the apophysial joints (Friedenberg et al 1959)

A great part of the literature on the normal and morbid anatomy of the cervical spine deals with the postero-lateral or unco-vertebral region of the disc and vertebra The reason for this is obvious because of the close anatomical relationship between this area, the foramen containing the nerve root and the vertebral vessels

Since Luschka (1858) described the region as a semi-joint (Halbgelenk) it is usually called the Luschka-joint' There has been a continuous dispute whether it is a true joint or just a degenerative phenomenon Trolard (1893) stated that the bony surfaces are covered by cartilage and Compère et al (1959) demonstrated in adult specimens all of the elements of a true joint including a joint space, articular cartilage and synovial tissue

Jackson claimed (1965) that the disc does not extend to the lateral and postero-lateral margin of the vertebral body and that there is articular cartilage and a well-defined capsular ligament but made no mention of a synovial membrane. Giraudi (1931) claimed in a purely roentgenological and clinical investigation to have demonstrated a joint. In opposition to "the true joint view" Rathke (1934) could not find the joint described by Luschka neither macroscopically nor microscopically. Frykholm (1951) thought that "unco-vertebral joints" genetically belong to the annulus because the apophysial ring completely covers the uncinate process, and all the structures enclosed between the apophysial ring must be equivalent to the annulus in other regions. Krogdahl and Torgersen (1940) doubted that it is adequate to use the word joint because the region lacks many of the criteria of a true joint but they chose the term because they thought it was the best way to describe the anatomical condition.

Many authors have in opposition to the joint hypothesis expressed their findings as fissures in the lateral part of the disc, (Rathke 1934, Krogdahl and Torgersen 1940, Tondury 1943, 1955, 1958, Frykholm 1951, Payne and Spillane 1957, Hadley 1957, Orofino et al. 1960, Ecklin 1960, Hall 1965, Silberstein 1965) and none of these authors has been able to demonstrate synovial lining in specimens from young individuals. The fissures are not found in specimens from foeti or new-born infants (Orofino et al. 1960, Hadley 1957). The postero-lateral space of this zone of the disc is filled with loose fibrous tissue (Rathke 1934), containing blood vessels (Tondury 1943, Hadley 1957, Ecklin 1960, Orofino et al. 1960, Hall 1965). At the age of 6—9 years the uncinate processes are beginning to grow and form and are fully developped at age 18 (Rathke 1934). During growth, fissures appear and are well established at age 14 (Tondury, Ecklin, Hall, Silberstein). Tondury (1958) stated that these fissures seem to be the start of centrally directed bigger fissures and Ecklin (1960) who summed up Tondury's earlier

work, pointed out that the fissures start in normal disc tissue They are the result of the function of the cervical spine With increasing age degenerative changes occur The surfaces of the fissures may undergo cartilaginous metaplasia forming a "neoarthrosis" where Silberstein (1965) in specimens from the 7th decade of life found tissue that appeared to have synovial characteristics

Most authors agree that arthritic changes in this region are frequent and appear early in life Spur formation directed backwards or laterally narrows the intervertebral foramen (Krogdahl and Torgersen 1940, Hadley 1957, Payne and Spillane 1957, Orofino et al 1960) and may compress the vertebral artery (Krogdahl and Torgersen 1940) There is a high degree of correlation between arthritic changes here and disc narrowing at the same level Many investigators find these changes to be only part of a general disc degeneration and not an isolated phenomenon (Giraudi 1931, Frykholm 1951, Payne and Spillane 1957, Friedenberg et al 1959, Silberstein 1965)

The uncinate processes are considered to restrict sideward flexion (Frykholm 1951) or to help to prevent lateral or posterior subluxation and to serve as a barrier to postero-lateral extrusions of the disc (Compere et al 1959) The processes may also serve as a guide-raise during translatory motion (Ecklin 1960)

Material and Methods

This study is based on fresh human autopsy material A total number of 111 cervical spines were investigated

Individuals from all age groups were sampled Subjects known to have malignant disease with bone metastasis were excluded *The study group is described in Fig 2 and Table 1*

All the spines studied were obtained within 48 hours following death

All together close to 700 discs were investigated and more than 3000 microsections studied

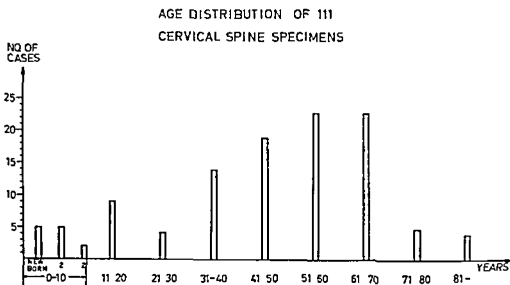


Fig 2

TABLE 1

Age group	Case number	Age	Sex	X ray	Cause of death
0—10	1	1 day	M	x	Aspiration Pleurisy Atelectasis
	2	1	M	x	Aspiration Pleurisy Atelectasis
	3	1	M		Foetus maceratus
	4	2 days	M	x	Pneumothorax Mediastinal emphysema Atelectasis
	5	4	M	x	Congenital heart failure
	6	7 months	M	x	Bilateral encephalopathy Broncho pneumonia
	7	7	F		Congestion of lung and circulatory failure
	8	14	F	x	Increase of intracranial pressure
	9	2 years	F		Subtentorial tumour of the brain
	10	2	F		Meningococcal meningitis
	11	7	F	x	Encephalopathy Broncho pneumonia
	12	10	F		Circulatory failure
11—20	13	11	F	x	Brain tumour
	14	11	M	x	Extradural haematoma
	15	14	F	x	Oliguria and uremia
	16	15	F	x	Aneurysm of carotid artery
	17	15	F	x	Oesophageal varices with haemorrhage
	18	16	M	x	Acute leukaemia Broncho pneumonia
	19	18	M	x	Cancer of the nasal cavum
	20	19	M	x	Fat embolism in lung and brain
	21	20	M	x	Cerebral haemorrhage
21—30	22	22	M		Information missing
	23	24	M	x	Rupture of the aorta
	24	25	F	x	Information missing
	25	28	F	x	Cerebral tumour
31—40	26	32 ,,	F	x	Venefitium
	27	32 ,,	F	x	Information missing
	28	33	M	x	Glioma of the cerebellum

Age group	Case number	Age	Sex	X ray	Cause of death
	29	34 years	M	x	Aspiration pneumonia
	30	34	F	x	Circulatory failure
	31	34	M	x	Cholangitis with jaundice Partial hepatectomy
	32	35	F	x	Sequelae of right sided nephrectomy Pyonephrosis and broncho pneumonia
	33	36	F	x	Gastric cancer
	34	36 ,	M	x	Rupture of the aorta
	35	37	M	x	Broncho pneumonia Pulmonary embolism
	36	37	I	x	Malignant tumour of gallbladder
	37	38 ,,	F	x	Mammary cancer with metastases in lymph glands Circulatory failure
	38	40 ,	I	x	Gangraenous granuloma
	39	40	M	x	Malignant abdominal tumour
41—50	40	41 ,,	F	x	Uremia
	41	43	F	x	Intracranial arterial aneurysm with haemorrhage
	42	43	M	x	Pulmonary embolism
	43	44 ,	F	x	Bronchial cancer
	44	44	M	x	Myocardial infarction and cardiac failure
	45	47 ,,	F	x	Circulatory failure
	46	47	F	x	Ovarian cancer
	47	47	M	x	Reticular sarcoma of the nasal pharynx
	48	47	F	x	Uremia and pulmonary congestion
	49	48	F	x	Cancer of the colon
	50	48 ,,	F	x	Chronic pyelonephritis
	51	49 ,	M	x	Pneumonia
	52	49	M	x	Intestinal fistulas with intraabdominal abscesses
	53	49	F	x	Ovarian cancer with liver metastases
	54	49	F	x	Tuberculosis of the lungs and respiratory and circulatory failure
	55	50	F	x	Cancer of the choledochus cholangitis

	56	50 years	M	x	Uremia Chronic pyelonephritis
	57	50	M	x	Chronic glomerulonephritis with uremia
	58	50	F	x	Cancer of the choledochus with cholangitis
51—60	59	52	F		Cerebral haemorrhage
	60	52	M	x	Cancer of the lungs and broncho pneumonia
	61	52	M	x	Pulmonary embolism
	62	52	M	x	Prostate cancer
	63	53	F	x	Malignant renal tumour and broncho pneumonia
	64	53	M		Cerebral contusion
	65	53	M	x	Broncho pneumonia
	66	53	F		Cancer of the rectum and metastases of the lungs
	67	53	F		Encephalomalacia and broncho pneumonia
	68	54	M	x	Cerebral tumour
	69	54	F	x	Chronic pyelonephritis and uremia
	70	55	F	x	Pleuropneumonia
	71	55	M	x	Broncho pneumonia
	72	55	F	x	Tuberculosis of the lungs and cachexia
	73	56	F	x	Cancer of the right breast
	74	56	M	x	Uremia
	75	56	F	x	Subarachnoid haemorrhage
	76	57	M	x	Myocardial infarction
	77	57	F	x	Gastric cancer
	78	57	F	x	Cerebral tumour and pyelonephritis
	79	57	F	x	Cerebral tumour
	80	58	F	x	Cancer of the lungs
	81	60	F	x	Cardiac failure Thrombosis in superior mesentary artery with infarction of *intestine*
61—70	82	61	M	x	Acute leukaemia
	83	61	F	x	Uremia
	84	62	F	x	Pancreatic cancer Hepatic cirrhosis
	85	62 "	M	x	Pulmonary cancer Congestion of the lungs
	86	63 "	M	x	Operated cancer of stomach

Age group	Case number	Age	Sex	X ray	Cause of death
	87	63 years	F	x	Operated cancer of the breast Abscess of the lungs and broncho pneumonia
	88	63 ,,	M	x	Embolism of the pulmonary artery
	89	63	M	x	Cardiac failure
	90	64	M	x	Respiratory failure with cardiac failure
	91	64	F	x	Aneurysm of the right medial cerebral artery
	92	64 ,,	M	x	Pancreatic cancer
	93	64 ,	F	x	Malacia of cerebrum
	94	65	M	x	Myocardial infarction
	95	65	M	x	Information missing
	96	66 ,	F	x	Periarteritis nodosa and subacute nephritis Pancreatitis Broncho pneumonia
	97	66	F	x	Cardiac failure
	98	66	M	x	Cirrhosis of the liver with oesophageal varices and gastro intestinal haemorrhage
	99	67 ,	F	x	Cancer of the breast Embolus of the pulmonary artery
	100	67 ,	F	x	Myocardial infarction
	101	68 ,,	F	x	Myocardial infarction
	102	68 ,	M		Cerebral haemorrhage and broncho pneumonia
	103	68 ,,	M	x	Arthritis urica with nephropathia
	104	70 ,	F	x	Cancer of the pancreatic head
71—80	105	71	F	x	Uremia
	106	72 ,,	M	x	Pulmonary embolism
	107	76	F	x	Myocardial infarction
	108	76	F	x	Circulatory failure
	109	77 ,	M		Cancer of the prostate and liver with jaundice
81—	110	84 ,	F	x	Cardioarteriosclerosis and cystopyelonephritis
	111	96 ,	F	x	Cardiac rupture

At post-mortem examination cervical spines were removed from the first cervical to the first thoracic vertebra The specimens were then X-rayed in the A P, lateral and oblique projections

With a band saw a thin sagittal slab, approximately 4 mm thick, was cut from the midline of the specimens (Fig 3 1) This section was planned to allow study of the subchondral bone, the cartilage end-plates, the anterior and posterior annulus fibrosus and longitudinal ligaments and the nucleus pulposus at each disc level

From one of the remaining lateral segments a new 4 mm thick slab was sawed off along a plane perpendicular to the neural foramina, including these foramina and the intervertebral joints in the slab (Fig 3 2) The apophysial joints, the neural foramina and nerve roots, the unco-vertebral processes and postero-lateral aspect of the intervertebral discs and vertebrae were then available for study on one same section

The remaining lateral segment was sectioned horizontally at the level of each intervertebral disc and slabs 4 mm thick were removed (Fig 3 3) These blocks presented the nerve roots and ganglia, the apophysial joints, the unco-vertebral processes, the lateral aspect of the intervertebral disc and the vertebral arteries In a small number of specimens a slab cut along the frontal plane was obtained (Fig 3 4)

Contact X-rays on Kodak type R industrial film and colour and black and white photographs were made of each one of the sections described

The specimens were then divided in small blocks including each an intervertebral disc and neighbouring structures and fixed in 10% formaldehyde and decalcified in Parenghi s solution or 10 % nitric acid

Following decalcification the blocks were embedded in paraffin and sectioned for histological study Hematoxilyn Eosin and PAS stains were used on the histological sections

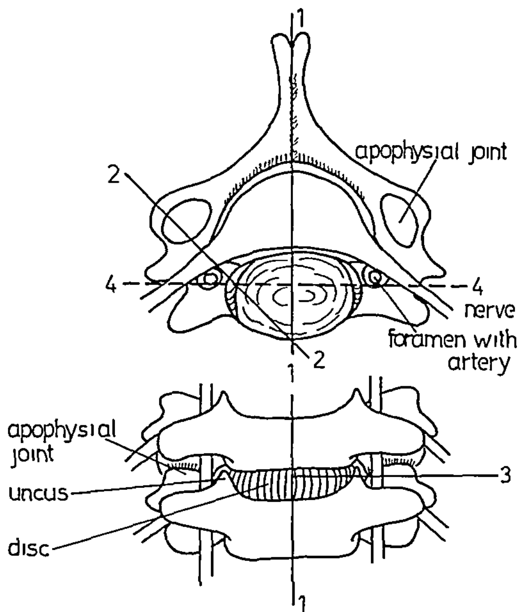


Fig 3 Drawing illustrating how the specimens were cut

Discograms

Following removal from the body, in 10 spines, discograms were performed Each intervertebral disc was punctured antero-laterally with a fine needle (same caliber as the one used in clini-

cal discography) and 0 2 cc of contrast U (perabrodil) injected slowly into the disc space X-rays were then taken in the A P, lateral and oblique projections The specimens were then processed in the manner previously described

Vascular perfusion studies

In 10 spines perfusion studies of the arterial systems were made Following the post-mortem examination both vertebral arteries were catheterized in the neck and ligated at the base of the skull

Perfusion through one of the catheterized arteries was performed with either one of two solutions a 30% suspension of Micropaque (finely divided barium sulphate) with 4% Berlin Blue, or a solution of 5% Berlin Blue Some specimens could not be perfused in situ and the same procedure was performed on the isolated cervical spine with its surrounding soft tissues immediately after removal No measurements of injection pressures were made

The spines were then X-rayed, fixed in 10% formaldehyde and decalcified in 10% nitric acid

Following decalcification the specimens were sectioned in slabs along the lines previously described Colour and black and white photographs of each slab were made and contact roentgenograms taken of the specimens injected with the barium suspension

The slabs were then cut in blocks including each a disc and related structures Each block was divided in two halves One half was processed for histological study, was embedded in paraffin, sectioned and stained with Hematoxylin-Eosin and PAS The other half was sectioned in a freezing microtome The sections were then processed according to the method of Spalteholz to clear the tissues and observe the vascular tree

The Formation of Discs and Vertebral Bodies

At the time of birth the ossified central part of the vertebral body has an ovoid shape and its height is less than the cartilage part of the body including the disc The cartilage end-plate is distinguishable and the nucleus pulposus and annulus fibrosus can be differentiated as separate structures (Fig 4) It is possible to see that the nucleus pulposus is slightly displaced posteriorly This is clearly seen in one of the specimens of 14 months (Fig 5) where an evident difference between the ventral and dorsal part of the annulus fibrosus exists The annulus is thicker and more compact anteriorly similar to the conditions of the lumbar disc Even the laminar structure of the cervical annulus fibrosus has the same pattern as in the lumbar spine described previously by Hirsch and Schajowicz (1952) The vascularization of the ossified vertebrae is very abundant but there are no vessels penetrating into the annulus fibrosus and nucleus pulposus as the histologic and angiographic studies demonstrate (Fig 6) Vessels penetrate into the cartilage part of the body before a clear differentiation from the cartilage end-plate has taken place Once it has been formed no vessels penetrate into it until the moment when the calcification of the lateral epiphysial nuclei starts This was observed in the 14- and 15-year-old specimens (Fig 7) There is a typical growing zone between cartilage end-plate and subchondral bone with only low columns of hypertrophic and proliferating cartilage cells

The first ossification holes (Schmorl's Ossifikation-Lucken) appeared in a 7 year-old specimen increasing their number in the 14 and 15 year-old cases (Fig 8) At this stage the calcified nuclei of the anterior and posterior marginal crest were already



Fig 4 Case number 5 Four day old infant
Topographic microphotograph of sagittal section of the 4th disc and adjacent bodies
The different components of the disc can already be identified a the cartilage end plate is high b the nucleus pulposus is located slightly posteriorly and the annulus fibrosus c is thicker anteriorly similar to conditions in the lumbar region (x 7)

Note

In all the pictures to follow the anterior part of the cervical spine or part of it is always to the right

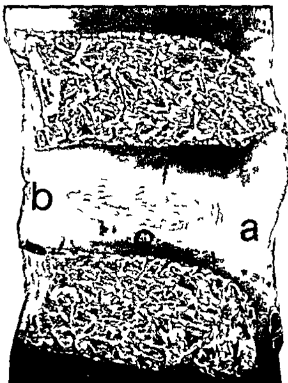
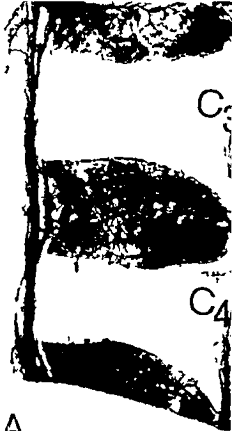


Fig 5 Case number 8 Fourteen month old child
Microphotograph of the 6th cervical discs and adjacent vertebrae
Sagittal section showing clearly the different components of the disc and the greater thickness of the anterior a than the posterior part b of the annulus fibrosus The cartilage end plates c are distinguishable from the nucleus pulposus

formed in several discs Sometimes the calcification extends irregularly in form of a discontinuous plate anterior and posterior over and in close contact with the ossification holes as has been described in the dorsal and lumbar spine by Schajowicz (1938) This phenomenon is not a sign of degeneration as Ecklin states but a normal condition during growth and calcification of the end-plates Once the calcified nucleus of the cartilage end-plates starts its ossification at its antero-lateral and posterior borders the marginal crest is formed and the calcified area in the central part of the disc disappears

Fig 6 Case number 10 Two-year old child
Microangiograms of C III and C IV and adjacent vertebral bodies (Berlin Blue and Spalteholz method)
A Sagittal section The vascularization of the osseous vertebrae is visible as well as small vessels penetrating into the cartilaginous portions of the bodies The nucleus pulposus and annulus fibrosus do not show any vascular connections
B Oblique section of the postero lateral portions of C III and C IV
a Intermedial growth cartilage between anterior and posterior parts of the osseous vertebral bodies are lacking vessels as well as the discs except the posterior indentations where numerous vessels b are approaching the disc from the foramen c
C Another section from C IV level at higher magnification







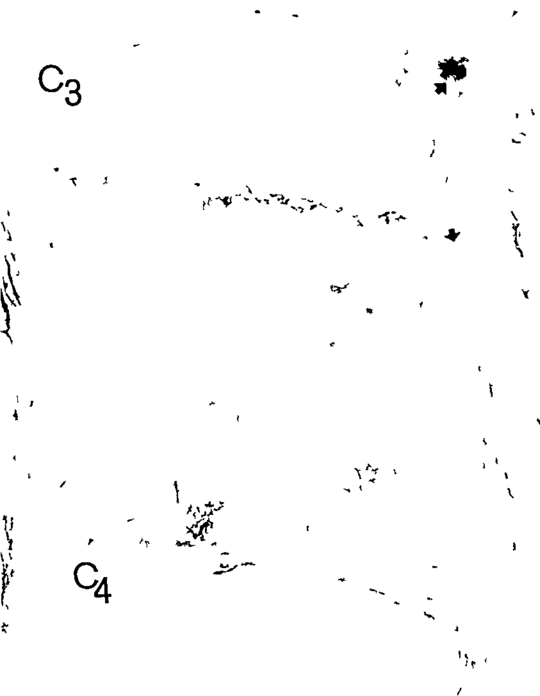


Fig 7 Case number 17 Age 14
Microangiogram of a sagittal section of C III and C IV (Berlin Blue and Spalteholz method)
The vascular pattern of the vertebral body is shown The cartilaginous end [illegible] the nucleus and the annulus are lacking vessels with exception of the [illegible]ior edges of the end plates where the osseous marginal epiphyses are being formed (arrow)

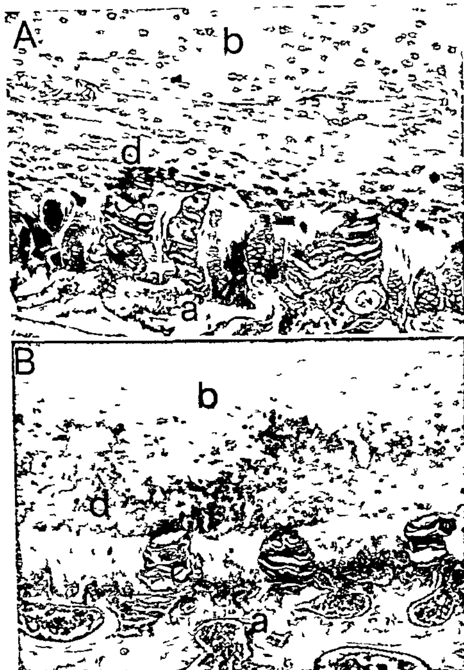


Fig 8 Case number 16 Age 15
Microphotograph of A C VI and B C VII illustrating the growth zone between vertebrae a and cartilage end plate b The classical ossification holes (Schmorl) c are interrupting the growth cartilage Irregular calcification areas d of different sizes partly discontinuous cover the region This is not a degenerative phenomenon but a normal finding in enchondral ossification in discs

The Unco-Vertebral Region

At the time of birth a wide zone of growing cartilage is present between the anterior and posterior parts of the ossified vertebral body where the future uncus will be formed which we prefer to call uncus-anlage Tondury and Ecklin named this area "vertebral arch epiphysial growth cartilage' and Jackson "intermedial growth cartilage The cartilage end-plate of the vertebral body covers this intermedial growth cartilage and extends up to the inner border of the uncus-anlage However, the outer line of the annulus does not reach so far and thus at this area a triangular shaped loose vascular connective tissue is formed proceeding from the foramen It occupies the space left between the cartilage end-plates (Fig 9 and 10)

At 14 months (Fig 11) the intermedial growth cartilage has clearly decreased in size and the cartilage end-plates extend up to the posterolateral border of the uncus-anlage while the annulus ends at some distance more ventrally The same loose vascular connective tissue containing some thicker vertical collagen bundles, fills the space between the thinned postero-lateral portions of the cartilage end-plates reaching the uncus border The angiograms of the 2 year-old specimen (Fig 6) illustrate the great number of vessels at this zone between the disc and the paravertebral tissues from the foramen In this age group no fissure of joint-like space formation was found

At age seven (Fig 12) the intermedial growth cartilage has disappeared and both portions of the vertebral body are fused The uncus which is already formed and slightly elevated is covered up to its postero-lateral border by the cartilage end-plate like the lower surface of the above vertebra ("Gegenpol" of

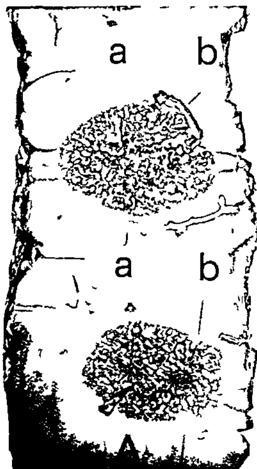


Fig 9

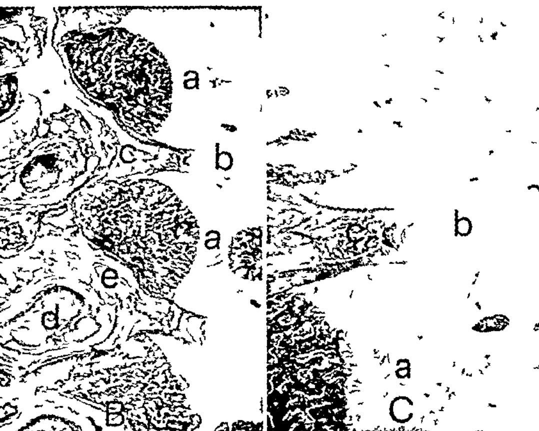


Fig 9

Fig 9 Case number 1 One day old baby
A and B Topographic microphotographs
A Sagittal section of the 5th and 6th cervical discs and adjacent vertebral bodies In the disc area different structures can be observed corresponding to the nucleus a and annulus b A great part of the vertebra is cartilaginous The vessels penetrate ventrally and dorsally only through the cartilaginous vertebral bodies into the ossified centres but not into the nucleus and annulus (x 8)
B Oblique section of the 5th and 6th discs and adjacent bodies in the postero lateral region a represents the growth cartilage area between the anterior and posterior portion of the uncus anlage f of the vertebral body This is called Wirbelbogenepiphyse by *Tondury* and intermedial cartilage by *Jackson*
At this stage the disc b does not reach the posterior area of the vertebral body The uncus anlage f is in contact with loose vascular connective tissue c pene trating from the vertebral foramen where nerve d and vascular elements e can be seen (x 8)
C Area of the 5th disc b at higher magnification illustrating the relationship between intermedial growth cartilage a and the loose connective tissue c from the intervertebral foramen e and f are the anterior and posterior portions of the osseous vertebral body (x 22 5)

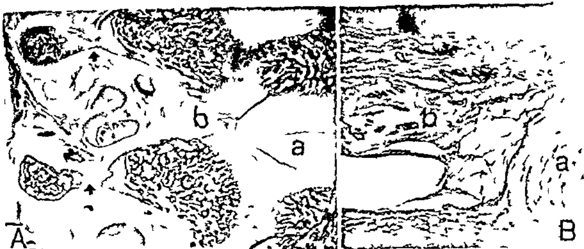


Fig 10 Case number 5 Four days old infant
A and B Microphotographs of oblique sections of the 4th disc The relationship of the various components of the foramen and the vertebral body are illustrated The arrow points at the vertebral arch The border zone of the disc a and the loose vascular connective tissue b proceeding from the foramen is shown at lower (x 9) and higher (x 90) magnification c uncus anlage

Fig 11 Case number 8 Fourteen month old child
A and B Oblique sections of the postero-lateral part of the discs The cartilaginous end plates a extend over the uncus anlage b while the annulus fibrosus c ends a short distance before d intermedial growth cartilage which has decreased in size e tissue e reaching the annulus c is located between the posterior cartilaginous end plates



Fig 12 Case number 11 7 year old child
Microphotograph of the postero lateral area of the 3rd disc The bony parts of the vertebra are fused a The uncus (arrow) is formed and has a ridge which is covered by the cartilage end plate b The same is seen at the vertebra above These borders are not reached by the annulus c because of an indentation containing the same vascular connective tissue d as described in the younger age groups e intervertebral foramen with ganglion nerve roots numerous veins and small arteries Where the annulus is in contact with the connective vascular tissue small fissures are seen in the annulus (x 9 5)

Tondury, ' Echancrure of French authors) These borders are not reached by the annulus because the triangular indentation still persists containing the same loose vascular connective tissue as described in younger age groups Where this area is in contact with the annulus, fibrillation and small fissures have been observed in the annulus extending slightly centrally Already at age seven a slight to moderate increase of basophilia could be noticed at the borders of some fissures but no evident alterations or proliferation of the surrounding cells could be demonstrated

In the 14, 15 and 18 year-old cases the fissures and cracks became more frequent, increased in size and width extending towards the nucleus These fissures were seen not only in the upper but also in several lower discs (Fig 13 and 14) At this stage the cartilage end-plates as well as the annulus reach the border of the uncus and its opposite pole However, the vascular connective tissue penetrating from the foramen into the disc is no longer quite of normal histological nature The annulus surrounding the fissures and clefts which are occasionally wide, forms a real cavity simulating a joint The annulus shows evident degenerative alterations with increase of basophilia of the fibers and metaplasia The cells become rounded, increase in size, being more recognizable as chondrocytes as they often have capsules or are multiplied forming clones In this manner a true joint space may be simulated but the alterations described are evidently secondary to the fissures A real synovial membrane has not been observed

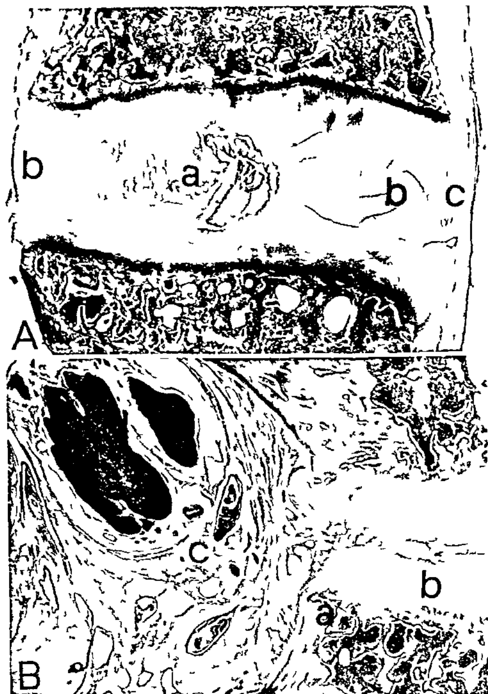


Fig 13 Case number 15 Age 14

A Microphotographs of sagittal section of C VI The nucleus pulposus a is lying more dorsally The annulus fibrosus b is much thicker and denser ventrally The anterior longitudinal ligament c is firmly attached to the annulus

B Oblique section of C III a uncus b disc c foramen A large horizontal fissure is reaching the posterior border of the disc and is in contact with the foramen



Fig 14 Case number 16 Age 1 Microphotographs of oblique sections of the unco-vertebral region of A C II B C IV and C C VI illustrating transverse fissures in the postero lateral part of the annulus of different size and shape in B simulating a joint space (Luschka joint) — see area marked by arrows

The Adult Cervical Spine

In the younger age groups no evidence of hypervascularization or vascular connective tissue reaction was found This reaction appeared first at age 24 and became more evident later in life In one case, age 35, many blood vessels mainly dilatated and hyperaemic capillaries, located in a more or less loose connective tissue could be seen, advancing from the foraminal tissue towards the fissured degenerated disc Similar reactions are common when radial posterior fissures and clefts appear extending as they quite often do from the nucleus pulposus to the posterior ligament (Fig 15, 16 and 17) This hypervascularized connective tissue in the posterior ligament reaching the radial fissures, is more frequently found after age 40 but was only present in about 20% of this material (Fig 18, 19 and 20) The same vascular reaction was found in the lumbar discs and described by Hirsch and Schajowicz (1952) However, in the early forties and not infrequently even earlier, advanced degenerative changes may appear, mainly mucoid degeneration, necrobiosis or necrosis, slight calcification accompanied by proliferative processes, such as hypertrophy and proliferation of cartilage cells especially around clefts and cracks of the nucleus

In the older age groups these clefts advance often ventrally and are commonly located near the lower marginal crest towards the anterior longitudinal ligament (Fig 21) However, most frequently the extension of the fissures is found dorsally communicating with large fissures dorso-laterally in the uncovertebral region (Fig 22 and 23)

After the fourth decade the cartilage end-plates frequently show degenerative changes of predominantly mucoid degenera-



Fig 15 Case number 23 Age 24
Photograph of oblique section from C IV and C V discs showing fissures in the posterior parts in the uncus area (arrow) penetrating into the central part of the disc

tion, circumscribed areas of increased basophilia, small horizontal or oblique clefts and cartilage cell hypertrophy and proliferation Although these degenerative changes are present in all discs, it is evident that the severe changes occur most frequently at C IV to C VI levels (Fig 24 and 25)



Fig 17 Case number 33 Age 36
A Microphotograph of a sagittal section of C IV showing a large horizontal fissure extending from the nucleus posteriorly reaching the posterior longitudinal ligament
B Oblique section of the disc showing the fissure in the unco vertebral area The fissure enters into the foraminal space and is surrounded by a dense fibrous tissue simulating an articular capsule a (x 9 5)

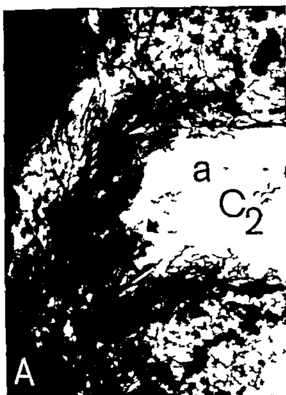






Fig 18 Case number 44 Age 44
Microangiograms of A-C II B-C III and C-C IV (Berlin Blue and Spalteholz method) Oblique sections showing the uncus area and degenerated discs a Numerous vessels from the foramen are advancing towards the discs (arrow)

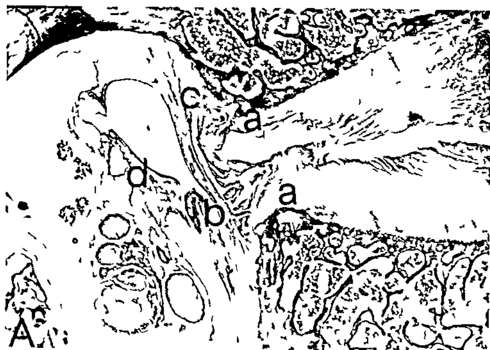


Fig 19



Fig 19 Case number 45 Age 47
Microphotographs at lower A (x 9 5) and higher B (x 115) magnification of C III illustrating changes accompanying extensive fissures and cavities in the postero lateral portion of the disc a beginning osteophyte formation b and c vascular connective tissue coming from the intervertebral foramen d approaching the disc fissures
B Zone c from Fig A at higher magnification showing the pronounced vas cularization and hyperaemia

Fig 20



Fig 20 Case number 56 Age 50
Microphotograph of sagittal section of C V at lower A (x 9 5) and higher B (x 120) magnification The pictures illustrate the posterior parts of the disc The disc is extensively degenerated a numerous fissures reaching the posterior longitudinal ligament b Newly formed capillary vessels are penetrating towards the degenerated disc The border between the disc and subchondral bone is completely irregular and the end plate is interrupted at c d and e osteophyte formation at the posterior ridges of the vertebrae
B Higher magnification of area b Capillary vessels approaching the degenerated disc
C Oblique section showing identical severe degenerative lesions of the disc a and the secondary alteration of the subchondral bone and osteophyte b and c The apophyseal joint d shows only moderate arthritic changes

A

Fig 21



Fig 21



Fig 21 Case number 63 Age 53
A Lateral and oblique radiographs The C IV and C V discs are degeneratec with pronounced osteophytic reactions anterior and postero lateral in the unco vertebral areas (arrow)
B Photograph of sagittal section of the C V disc showing the advanced de generative changes in the disc and the big osteophytes ventrally
C Microphotograph illustrating the destructive changes of the disc the ir regularity of the osteocartilage border the massive formation of osteophytes specially ventrally where intraligamentous ossifications are present (arrow)
D Microphotographs of the oblique section of the same disc a degenerated and narrowed disc surrounded by heavy bony sclerosis b c osteophyte posteriorly narrowing the space of the intervertebral foramen d In spite of the advanced disc changes the apophyseal joint shows only moderate arthritic lesions e



Fig 22 Case number 65 Age 53

A Photograph of oblique section of the postero lateral region through the uncus area of C III The disc is degenerated with a large fissure from the nucleus to the foramen

B and C Microphotographs at lower B and higher C magnification

C (× 23 5) showing a cavity in the disc at the uncus zone From the foramen vascular connective tissue is entering into the cavity simulating a synovial villus The cartilaginous end plates have remained but show degenerative changes This condition can be mistaken for a true joint with arthritic lesions



Fig 23 Case number 77 Age 57
A Photograph of oblique section of C III showing the postero lateral part of the disc a fissures and defects in the disc b apophyseal joint with normal appearance c foramen
B and C Microphotographs of the uncus region of the above disc a rest of the cartilage end plate with degenerative alterations covering an osteophyte b at the uncus c an ... ular cavity in the disc approached by congestive newly formed vessels d ... from the foramen

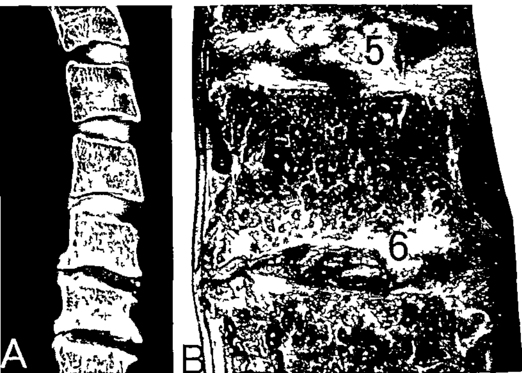


Fig 24 Case number 100 Age 67
A Radiograph of a 4 mm sagittal section The degenerative changes are most pronounced at C V and C VI levels
B Photograph of sagittal section showing the discs at C V and C VI
C Topographic microphotograph of C VI showing very advanced degenerative and proliferative alterations of the disc and adjacent vertebral bodies The disc is centrally replaced by dense fibrous tissue containing numerous newly formed vessels a coming from both vertebral bodies
D Higher magnification of the above area
E Posterior portion of C VI a showing besides the heavily degenerative and proliferative changes bone sclerosis b osteophyte c and a cavity d like a joint space similar to those observed commonly in the uncus area

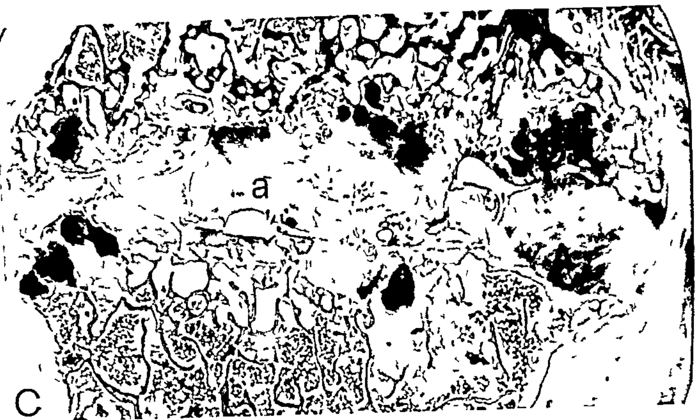


Fig 24





Fig 24

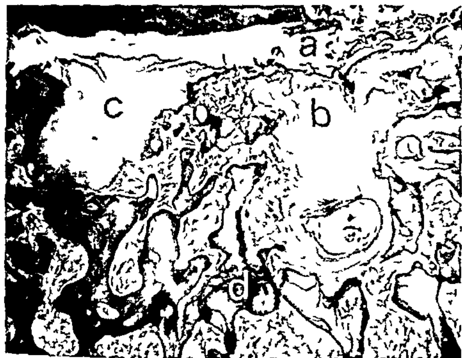


Fig 25 Case number 106 Age 72
Microphotograph of a heavily degenerated CV dis a subchondral fibrocystic alterations b and c bone marrow surrounded by clerotic bone trabeculae d These stru tural changes are identical to those found in osteoarthritis in real joints





Fig 24



Fig 26 Case number 97 Age 66
Microangiogram (Berlin Blue and Spalteholz method) C IV level Disc degeneration and ventral osteophytes There is evidently hypervascularization of this area

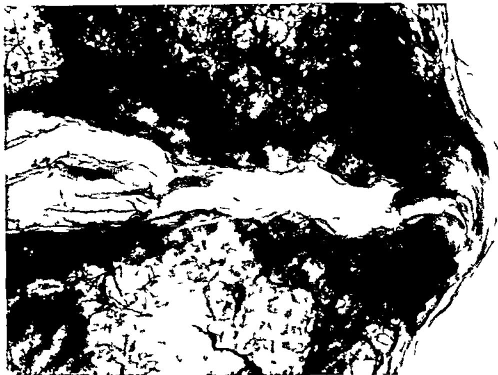


Fig 27 Case number 111 Age 96
Advanced disc degeneration of C V with formation of anterior osteophytes and irregular subchondral borders The hypervascularization of the bone marrow is intense with the exception of an area in the lower vertebral body which is either an ischaemic zone or may be an injection failure

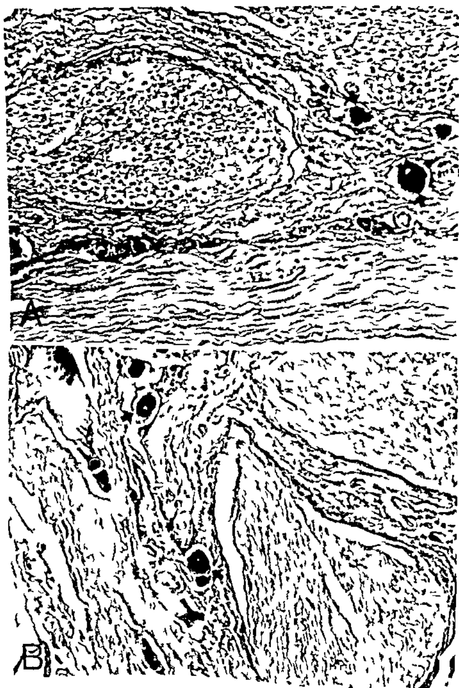


Fig 28
A Case number 56 Age 50
Microphotograph of calcified bodies of C V level in foraminal perineural and epineural connective tissue (x 180)
B Case number 63 Age 53
Microphotograph of calcified formations at C VII level similar to the [illegible] above (x 140)

generated cartilage end-plate shows an irregular increase in thickness of its calcified zone and ingrowth of blood vessels into the uncalcified areas of the cartilage end-plate and the disc itself Histological and angiographic pictures demonstrated an increase in number of mainly capillary dilated and hyperaemic blood vessels This is very similar to observations made by Harrison, Schajowicz and Trueta in arthritic hip joints However, the presence of a certain degree of passive hyperaemia, as Rutishauser claimed in arthritic hips, cannot be denied in the cervical spine as an additional fact

The vessels are often accompanied by a loose connective tissue gradually replacing the disc It may be followed by reactive new bone formation generally reaching only the cartilage end-plates In this way "central osteophytes' are formed The borderline between the disc and the subchondral bone becomes very irregular (Fig 24) Disc material may be displaced into the subchondral bone marrow which then shows fibrosis and cysts surrounded by sclerotic bone trabeculae (Fig 25) Subchondral bone sclerosis may however, sometimes be observed without disc protrusion or "cyst" formation

As mentioned earlier a similar histological pattern can be observed in unco-vertebral areas Only rarely do the penetrating vessels and the accompanying connective tissue of neighbouring vertebral bodies replace completely heavily degenerated disc tissue causing a fibrous union between the vertebrae A complete osseous fusion observed by other authors in very advanced disc degeneration has not been found

The apophysial joints were frequently less affected by arthritic lesions Different degrees and stages of the classical pattern of osteo-arthritis have been observed (Fig 29) There was no evident relationship between the degree of disc degeneration and osteophyte formation of the vertebral bodies and alterations in the apophysial joints

Discussion and Conclusions

Most of the patho morphological, radiographic and clinical attention has been centered around the postero-lateral part of the cervical spine, the so called unco-vertebral region due to its close relationship to the vertebral foramen with its nerve and vascular elements This area has been named by Luschka (1858) as hemiarthrosis intervertebralis lateralis and since then often called the Luschka-joint Many others like Trolard (1893) who introduced the name unco-vertebral joint and recently Jackson (1965) who adopted the term lateral intervertebral joint or lateral interbody joint to distinguish it from the posterior apophysial joint, accepted the anatomical fact of a true synovial joint But the great majority of investigators have joined Rathke s first classical presentation of 1934 stating that in the unco-vertebral region a real joint does not exist Most of the anatomical controversy is in fact due to the way in which this area has been examined Studies only in horizontal, sagittal or transverse sections do not give a clear view of the topographic morphology Our investigation adopting a combination of sagittal, horizontal and especially oblique sections which were examined radiologically, angiographically, macroscopically and histologically, proved that the unco-vertebral area is not a joint but has certain morphological characteristics simulating, during certain periods of life, a space covered by altered disc components and surrounded postero-laterally by fibrous tissue similar to a joint capsule but never covered by a synovial membrane

Early in life at 4 years of age (Hall 1965) or between 9 and 10 years of age (Tondury 1943, 1952 and 1955, Ecklin 1960) fibrillation and fissures in the annulus fibrosus of the uncus re

gion were seen which increased in size and extent with age and reached the nucleus pulposus According to Tondury this was more frequent in the upper cervical levels Since he considered these fissures to develop in normal and not degenerated disc material he felt that they constituted a biomechanical adaptation in order to increase the mobility of the upper cervical region

In our material we can confirm the early beginning of fissuration seen at age 7 From the age of 14 and on, they were constantly found varying in size and not only present in the upper disc levels but also frequently at the lower discs Although it is true that in the 4-year-old case of Hall's and in our 7-year-old child the degenerative changes in the annulus only constitued an irregular increase of basophilia in the neighbourhood of the fissures, the signs of degenerative changes in the annulus fibrosus were obvious after age 14 The fact that fissures constantly are present early in life, connecting inner parts of the discs with postero-lateral regions, allowing leakage of contrast media into foraminal and posterior areas at many disc levels in the same subject eliminates the clinical value of discography as a mean of identifying significant disc pathology This is in complete agreement with and confirms the findings by Holt (1964) in clinical material and normal controls

Since the annulus fibrosus and the nucleus pulposus of the cervical discs according to our findings are from the time of birth avascular tissues, degenerative alterations may occur early similar to those described by Hirsch and Schajowicz (1952) in the lumbar spine If and to what extent mechanical factors contribute to the development of these changes has as yet not been explained

Attention has been paid by several authors to the relationship of the annulus fibrosus and the nucleus pulposus at different ages This investigation showed that already in the newborn these components can be distinguished and that the time when a child starts to sit is not determinative for the differentiation as stated by Übermuth (1929) At 14 months of age the

annulus is evidently thicker and more compact ventrally than it is posteriorly and the nucleus is located posteriorly in relation to the middle of the disc This finding is contrary to Jackson's but in agreement with other investigators and similar to the conditions in the lumbar discs

The fissures and cracks so commonly seen in the young age groups extend and increase mainly posteriorly and postero-laterally towards the unco-vertebral area Often they cause secondary reactions in neighbouring paravertebral foraminal tissue and the vertebral borders

The first type of reaction to disc degeneration is the production of highly vascularized connective tissue surrounding and penetrating towards the degenerated fissured areas of the discs This phenomenon, however, is not constant and varies in extent and location and did occur in approximately 20% of this material

The osteophyte formation of the vertebral borders is the second important consequence of the disc alterations They were found not only ventrally but even more frequently in the postero-lateral area The osteophytes together with the histological, degenerative and proliferative alterations of the disc tissue surrounding the spaces and fissures give to this area the typical appearance of an arthritic joint

Quite often these postero-lateral osteophytes narrow the foraminal space In our material, however, we have not found evidence of mechanical deformation of the ganglion and nerve roots nor of the vertebral artery On the other hand perineural fibrosis was quite common sometimes especially in the elderly age groups accompanied by rounded deposits of calcium In no case did we observe cystic formations of arachnoidal origin described by Holt and Yates (1966)

In advanced disc degeneration generally accompanied by narrowing of the disc, subchondral bone and cartilage end-plate reactions appear with the ingrowth of blood vessels into the disc passing through the often irregular enlarged calcified zones of

the end-plate The vessels are accompanied by connective tissue replacing the disc and sometimes causing a fibrous union between the vertebrae The borderline between disc and subchondral bone becomes very irregular Disc material may be displaced into the subchondral bone marrow where fibrosis and cyst formation surrounded by sclerotic bone trabeculae are often seen This picture was also found in our material in the uncovertebral area and is very similar to the histo-pathology of osteoarthritis

Apophysial joints were strikingly less frequently affected by osteoarthritis and there was no relation between the amount of disc lesion, osteophyte formation and alterations in the apophysial joints

Structural changes in the cervical discs which take the form of progressive degenerative changes are usual phenomena which begin during adolescence and continue throughout life and are most probably related to the fact that the disc lacks a direct vascular supply The earliest changes consist of postero-lateral and posterior fissures in the disc tissue When the disc degeneration has reached a certain degree, the surrounding tissue reacts Highly vascularized connective tissue of the type of granulation tissue is formed This approaches the disc, then first beginning in the posterior and postero-lateral regions, penetrates and infiltrates the disc tissue The vertebral bodies also exhibit structural alterations Initially, in areas adjacent to the disc, an increase in the number of vessels is observed Subsequently osteophyte formation, central and marginal, and subchondral bony alterations, sclerosis, occur These changes are similar to the pathomorphological alterations of osteoarthritis in true joints

The formation of vascular connective tissue, of the type of

granulation tissue could explain pain experienced by the patient as this tissue is supposed to contain nerve elements

Radiating pain may be due to the influence of this "granulation tissue" on neural elements in the intervertebral foramen

As granulation tissue matures, it becomes less vascular and cicatrization occurs This could explain the recovery from pain which occurs spontaneously in a certain number of patients or which follows conservative treatment or surgical interventions

The pathomorphological changes and the clinical behaviour of both the cervical and lumbar spine have many obvious similarities, and generally speaking in both the pattern of pathomorphological changes is, in its advanced stages, that of osteoarthritis

Die strukturellen Veranderungen der Halswirbelbandscheiben in der Art von progressiven degenerativen Veranderungen sind habituelle Prozesse die im Jugendalter beginnen und wahrend des ganzen Lebens fortschreiten, Sie sind hochstwahrscheinlich durch die fehlende Gefassversorgung der Bandscheiben verursacht Die fruhesten Veranderungen bestehen in postero-lateralen und hinteren Spaltenbildungen des Bandscheibengewebes Wenn die Bandscheibendegeneration einen gewissen Grad erreicht hat, reagiert das Nachbargewebe und ein gefassreiches Bindegewebe vom Typ des Granulationsgewebes wird gebildet Dieses wuchert gegen die Bandscheibe und dringt in dasselbe verschieden tief ein, was zuerst hinten und hintenseitwarts beginnt

Auch die Wirbelkorper zeigen strukturelle Veranderungen, die mit einer Zunahme der Gefasse in der subchondralen Zone beginnen Anschliessend erscheinen Veranderungen (Sklerose)

der Spongiosa und Osteophytenbildung Diese Veranderungen sind vergleichbar mit der Artrosis deformans in wahren Gelenken

Die Bildung des reaktionellen gefassreichen Bindegewebes, nach Art eines Granulationsgewebes, konnte den Schmerz der Patienten erklaren, da anzunehmen ist, dass dieses Gewebe Nerven enthalt

Ausstrahlende Schmerzen konnten auch durch den Einfluss dieses "Granulations-Gewebes" auf die neuralen Element des intervertebralen Foramen verursacht werden

Wenn ein Granulationsgewebe reift wird es gefassarmer und es vernarbt Auf diese Weise konnte das spontane Verschwinden der Schmerzen oder nach l onservativer oder chirurgischer Behandlung, erklart werden

Das patologisch-anatomische und das klinische Bild der Lenden- und Halswirbelsaulenveranderungen zeigen deutliche Ahnlichkeiten und entsprechen in seinen fortgeschrittenen Stadien der Artrosis deformans der wahren Gelenke

Alteraciones estructurales de los discos cervicales en forma de lesiones degenerativas progresivas, constituyen un fenomeno habitual que comienza en la adolescencia y continúa en forma progresiva durante toda la vida, se deben con mayor probabilidad al hecho que el disco intervertebral no posee una vascularizacion propia

Las primeras alteraciones consisten en fisuras postero-laterales y posteriores del tejido discal Cuando el proceso de degeneración discal adquiere cierta intensidad, los tejidos vecinos reaccionan y se produce un tejido conectivo ricamente vascularizado, del tipo del tejido de granulación Este avanza hacia el

disco y comienza a penetrar dentro del mismo, primeramente en la región posterior y postero-lateral

Los cuerpos vertebrales muestran también alteraciones de su estructura Al comienzo se observa un aumento del número de vasos sanguineos en las areas adyacentes al disco, seguido por alteraciones del tejido oseo esponjoso subcondral y formacion de osteofitos centrales y marginales Estas lesiones son muy semejantes a las alteraciones morfologicas que se observan en las osteoartritis (artrosis deformante) de las verdaderas articulaciones

La formacion de un tejido vasculo-conectivo, del tipo del tejido de granulacion, podria explicar el dolor que experimenta el paciente ya que puede suponerse que el mismo contenga elementos nerviosos

El dolor irradiado podria deberse a la influencia de este "tejido de granulacion' sobre los elementos nerviosos del foramen intervertebral

Cuando un tejido de granulacion madura desaparecen paulatinamente los vasos sanguineos y se produce su cicatrizacion Esto podria explicar la desaparicion del dolor, lo que puede ocurrir espontaneamente o después de un tratamiento conservador o quirurgico

Las alteraciones anatomo-patologicas y el comportamiento clinico de la columna lumbar y cervical presentan muchas y evidentes semejanzas y en lineas generales el tipo de las lesiones corresponde en sus etapas avanzadas a la de una artrosis deformante

Des changements structuraux des disques cervicaux en forme de lesions degeneratives progressives constituent un phenomene ordinaire qui apparait des l adolescence et continue progressive-

ment pendant toute la vie, avec la plus grande probabilité ces changements sont dus au fait que le disque intervertébral manque d une vascularisation propre

Les premiers changements sont des fissures postéro-latérales et postérieures du tissu discal Quand le proces de dégénération discale atteint une certaine intensité les tissus voisins réagissent et il se produit un tissu conjonctif richement vascularisé, qui a le caractere du tissu de granulation Celui-ci s'avance vers le disque et commence a y pénetrer, d abord dans la région posté rieure et postéro-laterale

Aussi les corps vertébraux montrent des changements de leur structure On voit d'abord une augmentation du nombre des vaisseaux sanguins dans les parties adjacentes au disque, et plus tard des changements du tissu osseux spongieux subcondral et une formation d'osteophytes centraux et marginaux Ces lesions sont tres semblables aux changements morphologiques, qu'on voit dans les arthroses deformantes des articulations véritables

La formation d'un tissu vasculo-conjonctif, du caractere du tissu de granulation, pourrait expliquer la douleur qu'éprouve le malade, parce qu'on peut supposer que ce tissu contienne des éléments nerveux

La douleur irradiee pourrait être due a l'influence exercée par ce "tissu de granulation" sur les élements nerveux du trou intervertebral

Quand un tissu de granulation mûrit, les vaisseaux sanguins desapparaissent graduellement et une cicatrisation se produit Cela pourrait expliquer la cessation de la douleur, ce qui peut arriver spontanement, ou après un traitement conservatoire ou chirurgical

Les changements anatomo-pathologiques et le comportement clinique de la colonne cervicale ressemblent beaucoup a ceux de la colonne lombaire et, en principe, le caractere des lesions correspond, dans ses étapes avancées, a celui d'une arthrose déformante

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From the Department of Orthopaedics (Head Professor G Wiberg)
University of Lund Sweden

Supination-outward rotation injuries of the ankle

A CLINICAL AND ROENTGENOLOGICAL STUDY WITH SPECIAL REFERENCE TO THE OPERATIVE TREATMENT

BY CARL AXEL CEDELL

MUNKSGAARD COPENHAGEN 1967

Translator H Cedell

Statistical adviser J Ringstrom

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PART III

ankle mortise anatomically in respect to ligamentous injuries and fractures?

2 How often have pseudarthroses occurred?

3 What are the most common operative complications and how often have they occurred?

4 Should the large dorsal tibial fragments be subjected to an osteosynthesis or do satisfactory reduction and retention occur, by the distal oblique fibular fracture being reduced and fixed in the exact position?

Part III

Can in the present material a clear relationship be pointed out between

1 poor clinical results of treatment and the occurrence of arthrosis deformans?

2 unsuccessful reconstruction of the joint and the occurrence of arthrosis deformans?

IV *Short historical survey*

Maisonneuve (1840) was the first to describe the mechanism of outward rotation injuries With the support of experimental surgical investigations he pointed out the occurrence of two quite different types of fractures of the fibula When the tibiofibular ligaments remained intact, a distal and oblique fracture of the fibula arose When the ligaments mentioned ruptured a high up or subcapitally situated fracture of the fibula occurred Maisonneuve was of opinion that it was the pressure of the talus on the anterior part of the lateral malleolus that caused the distal fracture which was not accompanied by any ligamentous or aponeurotic damage He also proved that continued outward rotation of the foot caused a fracture of the medial malleolus or a rupture of the deltoid ligament Hönigschmied (1877) described 22 cadaver experiments in which outward rotation of the foot caused the same types of fractures that had been observed by Maisonneuve He found however in 6 cases an avulsion of a bone fragment from the anterior tibial tubercle i e the origin of the anterior tibiofibular ligament This injury however only appeared in combination with the high situated fibular fracture The distal fibular fracture was not accompanied by any ligamentous injury but always originated distally to the attachment of the anterior tibiofibular ligament Honigschmied also found that the distal fibular fracture was of 3 different types namely a long oblique fracture a short oblique fracture and a combined transverse and oblique fracture Contrary to Maisonneuve he considered that the

fracture was caused by a powerful pulling action of the posterior talofibular ligament

Le Fort (1886) described 3 clinical cases of isolated rupture of the anterior tibiofibular ligament where the attachment in the fibula was detached with a bone fragment. He thought however, that this type of fracture was caused by pure supination violence His pupil le Roy (1887), by cadaver experiments showed that the anterior tibiofibular ligament at outward rotation of the foot can rupture with avulsion of fragments from the anterior tibial tubercle as well as the anterior part of the lateral malleolus

Stimson (1892) was the first to prove that the distal oblique fracture of the fibula is preceded by a rupture of the anterior tibiofibular ligament, which with a bone fragment i detached from its origin on the anterior tibial tubercle The same discovery was made by Quenu (1907) who however produced outward rotation violence to the supinated foot

In 1922 Ashhurst & Bromer published their important work on ankle fractures which for the first time were given a genetic classification They consider that the distal oblique fracture of the fibula which is both intra and extra articular, generally shows no or slight displacement, and that in practically every case it is not accompanied by a rupture of the anterior tibiofibular ligament Ashhurst also considers that the 2nd degree of the outward rotation injury consists of a rupture of the deltoid ligament or a fracture of the medial malleolus and that the 3rd degree consists of a fracture of the posterior tibial margin Ashhurst & Bromers work is to this day widely accepted both for the classification and for the treatment of ankle injuries Bishop (1932) totally agrees with the views of Ashhurst & Bromer

In 1942 Niels Lauge Hansen published his extensive and important work on ankle fractures On the basis of experimental surgical and roentgenological studies he divides up the outward rotation fractures into 2 different groups which he calls supination eversion fractures and pronation-eversion fractures The former occur by outward rotation [illegible] supinated foot and comprise 4 so-called stages Stage I consists of [illegible] of the anterior tibiofibular ligament with avulsion of fragments [illegible] anterior tibial tubercle, or from the lateral malleolus or also [illegible] these places simultaneously Stage II implies the [illegible] oblique fibular fracture Stage III is characterized by [illegible] part of the tibia in the form of periosteal ligamentous [illegible] ture varying in size through the part of the bone that [illegible] of the posterior tibiofibular ligament and the [illegible] Stage IV finally implies the occurrence of [illegible] of the medial malleolus or detachment of the [illegible] Hansen thus considers that the distal oblique fibular [illegible] preceded by

a rupture of the anterior tibiofibular ligament, and that the fracture of the dorsal tibial margin always precedes the medial injury which is in glaring contrast to earlier ideas His views were rapidly subjected to a great deal of criticism and it was particularly emphasized that the results obtained by cadaver experiments were not applicable to the living organism In his work on fractures of the posterior tibial margin, Hendelberg (1943) considers Lauge Hansen s stage division to be erroneous In several cases he can register outward rotation fractures with medial injuries, but with completely intact dorsal structures In his work, Magnusson (1944) agrees with the classification represented by Ashhurst & Bromer and considers like Hendelberg that the medial ankle fracture precedes the dorsal one He also criticizes Lauge Hansen s conception of supination-eversion, but agrees entirely with him, concerning the injuries of the anterior tibiofibular ligament *Magnusson was the first to make a far-reaching clinical analysis of* these ligamentous injuries Thus he considers that defectively healed anterior syndesmotic injuries, in a high degree promote the occurrence of arthrosis deformans in the ankle

Danis (1949) divides up the ankle fractures into 4 groups with regard to the position of the fibular fracture in relation to the tibiofibular ligaments He considers la fracture interligamentaire , i e , the distal oblique fibular fracture unaccompanied by a rupture of the anterior tibiofibular ligament to be the most common type of fibular fracture

In his monograph on ankle injuries Bonnin (1950) entirely accepts Hönigschmied s experimental works as well as Ashhurst & Bromer s classification He therefore considers that the anterior tibiofibular ligament never ruptures but that the distal oblique fibular fracture constitutes the first stage of the outward rotation injury He gives a system of classification *of his own for outward rotation fractures, which he divides up into 3* degrees of severity in respect to the site of the fibular fracture and the occurrence of so-called tibiofibular diastasis i.e rupture of the tibiofibular ligaments So although with important fundamental differences he brings together in one large group the injuries which Lauge Hansen calls supination eversion fractures and pronation eversion fractures which from a practical point of view creates confusion and lack of clarity Contrary to Lauge Hansen Palmer (1950) considers that the dorsal tibial fracture precedes the medial one while other authors such as Kristensen (1949, 1956), *B s röm (1952) Reimers (1953) Proctor (1954)*, Vasli (1957) Quigley (1959) and Klossner (1962) entirely adopt the classification of the former Watson Jones (1955) in conformity with Bonnin considers that the distal oblique fibular fracture occurs without ligamentous injury and without displacement Jergesen (1959) highly criticizes Lauge Hansen whose classification he considers to be a great measure of speculation taking into

consideration only extrinsic stresses disregarding the intrinsic ones due to muscle activity In conformity with Devlies (1959) and Calvetti (1960) he considers that the distal oblique fibular fracture is not accompanied by a rupture of the anterior tibiofibular ligament Also Soeur (1961) criticizes Lauge Hansen s cadaver experiments and presents a classification for the malleolar fractures of his own according to which the distal oblique fibular *fracture* can arise both by *rotation* and by *plantar flexion* He considers this fracture to occur uncombined with a rupture of the anterior tibiofibular ligament Rose (1962) is of opinion that Lauge Hansen s genetic classification is the only one acceptable especially for the reason that it draws attention to the ligamentous injuries accompanying the ankle fractures He considers however that the fracture of the posterior tibial margin has another genesis than that one outlined by Lauge Hansen Other authors *using the classification of the latter are Dinstl & Spangler* (1963) Cedell & Wiberg (1962) Cedell (1965) Lauttamus & Solonen (1965) and Burwell & Charnley (1965) On the basis of experimental investigations Hirsch & Lewis (1965) however maintain that the different components of an ankle injury more commonly appear simultaneously than in a certain sequence Weber (1963 1966) finally divides the ankle fractures according to the height of the fibular fracture in relation to the tibiofibular syndes*mosis* a *division as a principle based on Danis classification He considers* that the distal oblique fibular fracture is seldom combined with a rupture of the anterior tibiofibular ligament with the exception of the stage IV injury which in the presence of a dorsal tibial fracture is always combined with a rupture of the ligament mentioned

From what has been said above it is clear that supination outward rotation injuries are subjected to a keen discussion with often controversial *opinions* maintained by different authors Many *questions concerning* especially the pathological anatomy of the injuries are still unanswered and require still more investigation and consideration

PART I

Clinical and roentgenological diagnosis Operative studies of capsule, ligament, bone and cartilage injuries

V *Material and methods*

The material in this work includes all those cases of supination outward rotation injuries operated on at the Department of Orthopaedics Lund Hospital in the years 1958—1965 The material has been selected by care ful study of roentgenograms and also records and operation notes The in juries have been classified according to Lauge Hansen for the reason that the author has judged his system to be the best of those available even if some important questions—as is clear from Chapter III—ought to be subjected to further discussion and investigation The purpose of the operations has first of all been to reconstruct the injuries at which efforts have been made to devise as adequate a method as possible In connection with these operations one has also had the opportunity to analyse the pathologico anatomical changes of the ankle which has been made possible, especially as the ligamentous injuries have also been exposed at operation Practically every patient has been subjected to operative analysis and treatment Only in a few cases a year one has been obliged to avoid such measures by force of special circumstances for instance the presence of severe skin damage and serious somatic disease

A Clinical diagnosis

After the customary history taking the patients have been carefully examined by inspection palpation and function test The surgeon on duty has meanwhile filled up a special form of examination with his observa tions which has then accompanied the patient to the operating unit where the operator in question has made a note of the observations at the explora tion Thus one has registered the presence of deformation swelling hema toma and skin damage in the form of contusion nutritive disturbances and penetrating wounds The joint capsule ligaments and adjacent skeleton parts have systematically been palpated and the maximal point of tender ness and possible crepitations have been located Circulation and nerve

function in the foot have also been tested. Often a cautious stability test has been performed. In ligamentous injuries the maximal point of the indirect pain has often been explored by cautious provocation tests, i.e. displacement of the foot in certain directions. On the basis of the clinical symptomatology a preliminary diagnosis has been made in respect to the type and the stage of the ankle injury.

B. Roentgenological diagnosis

The roentgenological examination of the ankle has been performed according to a modification of the method reported by Bolin (1961) (see Fig. 1). Thus the examination has taken place in well defined projections and, apart from the early part of the patient material, the uninjured ankle has also been subjected to an exactly equivalent examination. 4 standard projections have been used, namely 1) 0° rotation, 2) 20° inward rota-

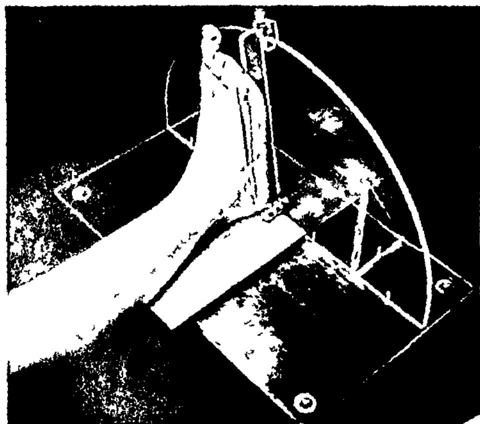


Fig. 1. Device used in the roentgenological examination of the ankle injuries. (From Bolin, H.: Acta radiol. 56, 1961, Fig. 5, p. 443.)

tion 3) 55 outward rotation and 4) 85° outward rotation of the leg and the foot These projections reproduce 1) the joint between the talus and the medial malleolus 2) *the joint between the talus and the lateral mal leolus* 3) the anterior tibial tubercle and 4) the posterior tibial process respectively When necessary complementary examinations in other projec tions have been made especially at the suspicion about the occurrence of a rupture of the deltoid ligament or a fracture through the dorsal part of the tibia A simultaneous *examination of the uninjured ankle has in many* cases yielded much valuable information particularly in respect to the diagnosis of ligamentous injuries Arthrography has not been used Stress roentgenograms i e examination of the foot forcibly twisted in various directions have occasionally been used in connection with the diagnosis of ligamentous injuries In the material with the *exception of the luxation in* juries the position on admission i e the position of the talus and of the bone fragments in the primary roentgenograms of the patients has not been registered According to the author s opinion these roentgenograms do not make an estimation of the severity of the injuries possible as the position of the talus and the bone fragments during the transport of the patient from the place of the accident to the roentgen examination table is mostly influenced by many external factors in a positive way

C Operative examination

Most of the patients have been explored within 1 to 3 days after admission Open injuries and several luxation injuries have been treated by emergency operation The patients have generally been operated on under spinal anesthesia and in a bloodless field Elderly people and patients with hyper tension and with suspected coronary disease have as a rule been operated on under general anesthesia some under local anesthesia As a rule a bloodless field has not been used in elderly patients and not in the presence of manifest or suspected obliterating vascular disease The lateral side of the ankle has been explored through a curved incision over the lateral side *of the distal fibula, extending to the anterior tibiofibular ligament* and the lateral part of the joint capsule see Fig 2 The medial part of the ankle has been explored either through a transverse curved incision or a vertical straight incision across the medial malleolus see Fig 3 As a rule the posterior tibial process has been explored from the lateral incision which *is then placed further dorsally than usual Occasionally this exploration* has also taken place through a separate incision just laterally to the Achilles tendon As neither the clinical nor the roentgenological examina tion could give a conclusive answer about the stage of the injury an ex tended exploration of the joint was made Thus the deltoid ligament has

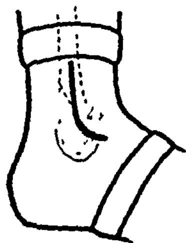


Fig 2 Lateral operative approach to the talocrural joint

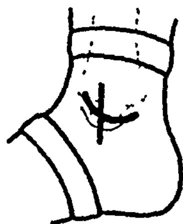


Fig 3 Medial operative approach to the talocrural joint

in many cases been explored in order to distinguish an injury of stage II or stage III from an injury of stage IV In several cases also the posterior tibial process has been explored so that information about the character of the dorsal injury has been obtained The distal oblique fracture has been carefully registered in respect to its origin and length and the displacement of the distal fracture fragment The anterior tibiofibular ligament has been subjected to a special interest and the whole ligament has been exposed The location of the rupture has been registered as well as the presence of avulsion fragments from the anterior tibial tubercle or from the lateral malleolus The stability in the interosseous tibiofibular ligament has also been tested On the medial side one has registered the appearance of the medial malleolar fracture the occurrence of interposition of soft tissue and the displacement of the malleolar fragment At the occurrence of a rupture of the deltoid ligament one has registered its position and extent, i e whether

the injury has been partial or total The joint capsule has been exposed from both incisions as extensively as possible and the injuries have been registered The facets of the talus have been examined especially in respect to the occurrence of subchondral fractures In the years 1961—1965 the isolated rupture of the anterior tibiofibular ligament has been subjected to special studies For this reason a great number of sprained ankles during these years has been operatively explored at which the lateral ligaments of the ankle have been exposed and the injuries to them have been registered

D Presentation of the material

1 *Size of the material in relation to all ankle injuries operated on*

The material in all comprises 417 supination-outward rotation injuries in 416 patients In all 735 ankle injuries have been operated on at the clinic during the years 1958—1965 417 of which have been supination outward rotation injuries and 94 injuries involving rupture of the anterior talofibular ligament often in combination with the calcaneofibular ligament Disregarding the last mentioned group the supination outward rotation injuries constitute 65 1 per cent of the total number of injuries operated on Concerning the annual distribution of the different groups of injuries see Fig 4 The injuries have been located in the left ankle in 216 and in the right ankle in 201 cases

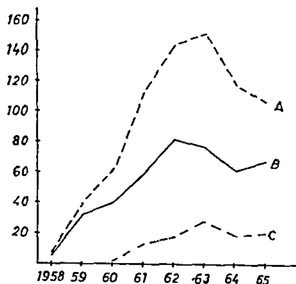


Diagram showing the cor
on between the total amount of
tively treated ankle injuries
e A) the number of operatively
d supination-outward rotation
es (curve B) and lateral
eral ligament injuries (curve C)
g the years 1958—1965

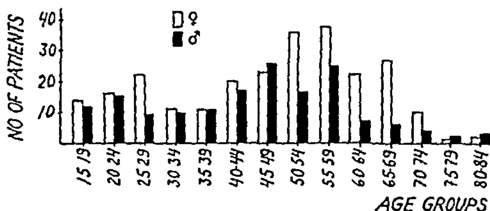


Fig. 5. Sex and age distribution of the patients. Marked predominance of women especially in the ages of 50 to 70.

2. Distribution of the patients into sex and age

The material involves 253 women and 164 men, which means a ratio of 1.5 : 1. The age of the patients varies rather strongly and within wide limits, the lowest age being 15 and the highest 84 years. Patients under 15 have not been included in the material, thus comprising adults only. Concerning the distribution of sex and age, see Fig. 5. The mean age of the whole material amounts to 46.3 ± 16.1 years, of which for the women 47.5 ± 16.1 and for the men 44.3 ± 16.7 years. The mean age of the women, accordingly, is somewhat higher than that of the men, but the difference is not statistically significant. In the ages between 50 and 70 there is a marked predominance of women.

3. Distribution of the patients into stage

The distribution of the injuries into different stages can be seen in Table 1. From this table it appears that there is a marked predominance of stage IV

Table 1. Stage distribution of the patients. Correlation to the year of operation.

Year	Stage I	Stage II	Stage III	Stage IV	Total
1958	–	2	1	2	5
1959	–	15	3	13	31
1960	–	16	3	20	39
1961	–	15	2	40	57
1962	2	28	3	48	81
1963	2	23	5	46	76
1964	4	21	3	33	61
1965	3	24	4	36	67
Total	11	144	24	238	417
%	2.6	34.5	5.8	57.1	100.0

and stage II injuries in the order mentioned while stage I and stage III injuries are rather modestly represented. The percentage distribution is Stage I 2.6 %, stage II 34.5 %, stage III 5.8 % and stage IV 57.1 %.

4. Correlation between sex, age and stage

The distribution of the patients in respect to sex, age and stage can be studied in Table 2. From this we conclude that a slight predominance of men is present in stage I, that the women dominate in stage II, that the distribution of sex is equivalent in stage III and that the women have a a very marked predominance in stage IV. The mean age in stage I is 30.2 ± 10.9 years and in stage II 42.4 ± 16.3 years. In the last mentioned stage the mean age of the women is 43.5 ± 17.4 years and that of the men 40.8 ± 14.9 years. The mean age of the women accordingly is a little higher but the difference is not statistically significant. In stage III the mean age is 44.2 ± 13.2 years. In stage IV it is 49.6 ± 15.7 years, the mean age of the women being 50.1 ± 15.5 years and that of the men 48.6 ± 16.0 years. Nor is the difference here statistically significant.

The mean age is higher*** in stage II than in stage I and higher*** in stage IV than in stage II. On the other hand there is no statistically significant difference between stage II and stage III and not between stage III and stage IV either. Summarily it can be said that stage I injuries are seen only in young patients and that the extent of the injuries is greater in patients of advanced age.

Table 2. Correlation between sex, age and stage

Age	Stage I ♀	Stage I ♂	Stage II ♀	Stage II ♂	Stage III ♀	Stage III ♂	Stage IV ♀	Stage IV ♂	Total ♀	Total ♂	Total ♀+♂
15—19	1	2	7	6	—	1	6	3	14	12	26
20—24	—	1	9	7	—	1	7	6	16	15	31
25—29	1	—	9	3	1	1	11	5	22	9	31
30—34	—	3	4	5	2	—	5	2	11	10	21
35—39	—	—	4	5	—	—	7	6	11	11	22
40—44	—	2	6	4	1	5	13	6	20	17	37
45—49	1	—	8	12	3	1	11	13	23	26	49
50—54	—	—	13	7	1	2	22	8	36	17	53
55—59	—	—	8	8	1	1	29	16	38	25	63
60—64	—	—	4	1	—	1	18	5	22	7	29
65—69	—	—	9	1	2	—	16	5	27	6	33
70—74	—	—	2	—	—	—	8	4	10	4	14
75—79	—	—	1	—	—	—	—	2	1	2	3
80—84	—	—	—	1	—	—	2	2	2	3	5
Total	3	8	84	60	11	13	155	83	253	164	417

Table 3 Stage distribution of the patients during the years 1962—1965 the Malmo patients excluded

Year	Stage I	Stage II	Stage III	Stage IV	Total
1962	2	28	2	30	62
1963	2	22	5	29	58
1964	4	21	3	33	61
1965	3	24	4	36	67
Total	11	95	14	128	248
%	4.4	38.3	5.7	51.6	100.0

5 *Frequency studies*

The distribution of the different stages of supination-outward injuries in a normal population is difficult to calculate but it can be roughly estimated From Table 1 it appears among other things that stage I injuries have not been registered before 1962 For that reason the percentage distribution of these injuries is too low In the material there are also included many patients who do not normally belong to the reception area From the Department of Orthopaedics Malmö General Hospital we have in the years 1961—1963 received 57 SOR injuries for treatment comprising 3 stage II 2 stage III and 52 stage IV injuries The addition of these patients gives the material an over representation of stage IV injuries During the years 1962—1965 the annual distribution of the different stages has been rather uniform If the Malmö patients from the years 1962—1963 are excluded one will get a correct distribution of the injuries of the reception area during the above mentioned period see Table 3 This material includes 248 patients The percentage distribution of the stages is Stage I 4.4 % stage II 38.3 % stage III 5.7 % and stage IV 51.6 % The sex distribution remains unchanged as compared to the whole operation material There may still be a slight over representation of stage IV injuries in the material as some severe ankle injuries have been transferred to the clinic from hospitals both in the reception area and out of it The percentage figures obtained could with consideration of the last mentioned circumstance indicate that the normal distribution of the different stages may be as follows 50 % stage IV injuries 40 % stage II injuries and 10 % stage I and stage III injuries with a slight predominance of the last mentioned

6 *Etiological factors*

At the history taking the patients were thoroughly questioned about the position and the movement of the foot at the moment of the accident Only 21 patients (5 %) spontaneously stated that the foot had been twisted out

Table 4 Etiological factors listed in order of frequency

		No of cases
1	Slipping on level ground (ice slippery or wet floor etc)	169
2	Slipping or stumbling down from a step	73
3	Sports injuries (Skiing 15 football 10 skating 7 wrestling 5 hand ball 2 sledging 2 gymnastics 2 and tennis 1 case)	44
4	Traffic accidents (overturned bicycles or motor cycles collision with bicycle motor-cycle or car)	35
5	Stumbling (trapping of the foot on locomotion)	32
6	Fall from a height	26
7	False step on rough ground	21
8	Fits of syncope (epileptic fit vaso-vagal fit insulin coma etc)	4
9	Other unspecified causes (rare types of trauma)	13
	Total	417

wards in relation to the lower leg 38 patients (9 1 %) stated pure supina tion violence to be the cause of the injury The rest about 85 per cent could not give any information at all as to how the foot had been dis placed at the moment of the accident especially because the occurrence of the injury was of very short duration Among the etiological factors there is a marked predominance of slipping on level ground which occurred in 169 cases (40 5 %) Next thereafter comes slipping or stumbling down from a steep 73 cases (17 5 %) In the third place come sports injuries 44 cases (10 6 %) More detailed information about the etiological factors is given in Table 4

7 *Comparison with earlier investigations*

Ad 1 The number of SOR injuries given an account of in this work will probably be the largest hitherto published Formerly Magnusson (1944) and Proctor (1954) have published materials comprising 386 and 400 patients respectively coming next in size The percentage occurrence of SOR injuries in the present work broadly speaking corresponds to ob-servations made earlier The percentage figures have in different materials varied between 42 0 and 73 6 Ashhurst & Bromer (1922) report 61 0 % Bishop (1932) 54 4 % Lauge Hansen (1942) 68 6 % Magnusson (1944) 48 8 % Kristensen (1949) 42 0 % Biström (1952) 73 6 % Vasli (1957) 73 6 % and Klossner (1962) 63 0 %

Ad 2 The distribution of sex among SOR injuries is very divergent Lauge Hansen (1942) mentions a slight predominance of women the ratio between women and men being 1 1 1 In his material Magnusson (1944)

has a slight predominance of men and the ratio between the sexes here is the reverse, i e, 1 1 1 In a material, comprising only stage III and stage IV injuries, Biström has a marked predominance of women the ratio being 2 5 1 As to the distribution of age Lauge Hansen (1942) considers that SOR injuries have a higher frequency in men and a uniform distribution in the different age groups up to the age of 45 After this age a pre dominance of women is present at the same time as the frequency of in juries is slowly decreasing The results in this work do not support this view There is in almost all age groups a predominance of women and the frequency of fractures clearly increases after the age of 45 The mean age of the patients in the present work is higher than that in Magnusson s material He reports a mean age of 42 2 ± 0 8 years of which for women 44 8 ± 1 2 years and for men 39 8 ± 0 9 years From this it follows that Magnusson also found a higher mean age for women than for men

Ad 3 Lauge Hansen (1942) has reported the following distribution of the different stages of SOR injuries stage I 4 3 %, stage II 35 0 % stage III 23 3 %, and stage IV 37 4 % Compared with this work there is a good accordance with the percentage distribution of the injuries of stage I and in a certain degree also with that of the injuries of stage II In Lauge Hansen s work however, the stage III injuries have a high representation and the stage IV injuries a low one The explanation of this must be that Hansen has divided up his material on a roentgenological basis only in consequence of which he has happened to place injuries with rupture of the deltoid ligament in stage III From this it appears that the distribution into stages must be based on both clinical and roentgenological examina tions Magnusson (1944) has divided up his material according to Ash hurst & Bromer thus using a roentgenological classification He has a high over representation of so-called unimalleolar fractures which correspond to stage II in Lauge Hansen s classification He also has an over representation of the combination of unimalleolar fracture and fracture of the dorsal tibial margin which then corresponds to stage III in the classification mentioned above Also these over representations will probably be due to the fact that sufficient attention has not been paid to the ruptures of the deltoid liga ment In a follow up material including 60 patients Kristensen (1949) has given the following stage distribution stage I 1 7 % stage II 28 3 %, stage III 13 3 % and stage IV 56 7 % Other materials published, for instance by Bistrom (1952) Vasli (1957) and Klossner (1962), only deal with so-called severe SOR injuries i e mainly stage III and stage IV injuries and in a certain degree also stage II injuries

Ad 4 In his material Lauge Hansen (1942) reports a predominance of female patients in stage I which does not agree with the observations in the present work 4 out of 7 patients in this stage were at an age under 45

He reports a male predominance in stage II and stage III which again does not agree with the observations in this work where in stage II there is a *female predominance* and where in stage III the sex distribution is uniform In stage IV Lauge Hansen reports a marked predominance of women which well agrees with the observations in the present work He also states that the injuries of stage IV especially affect women in middle life This last mentioned fact has also been reported by Bistrom (1952)

Ad 5 The distribution of the different stages of the SOR injuries in a normal population is not to be found in any earlier work The explanation of this would seem to be that no author before has made so thorough an inventory of the injuries as has been the case in this work

Ad 6 In his work Magnusson (1944) mentions that most of the SOR injuries in his material have occurred by the patients slipping or stumbling Thereafter follow in order road accidents and sports injuries Bistrom (1952) has above all emphasized the important rôle played by the trauma of slipping Thus he could prove that the majority of these injuries occurred during the winter months Several authors also report that a very small number of the patients can describe how their foot was displaced at the time of the accident

VI *Injuries of the anterior tibiofibular ligament*

A Isolated rupture of the anterior tibiofibular ligament (stage I)

1 *Different types of rupture*

In the medical literature little attention has been paid to the isolated rupture of the anterior tibiofibular ligament (ATFL) In a material comprising 31 ligamentous ankle fractures Lauge Hansen (1949) has described 4 cases of isolated ATFL-rupture which implies a frequency of about 13 per cent Bonnin (1950) considers that the isolated ATFL rupture is the most common ligamentous injury in the ankle often occurring in combination with a rupture of the calcaneofibular ligament Palmer (1950) is of opinion that the injury is a common type of ankle sprain McLaughlin (1959) considers the isolated ATFL rupture essentially to be a sports injury and terms it the skier s sprain Menelaus (1960) has reported clinical and operative findings in 3 patients 1 or possibly 2 of them however must have had a pronation injury with a simultaneous rupture of the deltoid ligament to judge from the roentgenograms which show a very great distance between the talus and the medial malleolus Brostrom (1966) has

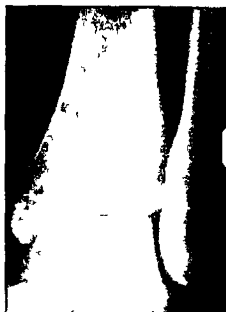



Fig 7 Rupture of the right anterior tibiofibular ligament in the ligamentous substance No bone fragment and no incongruity can be seen Left ankle in exactly the same projection for comparison



Fig 8 Stage I injury with an unusually large fragment from the anterior tibial tubercle

mental investigations with section of the ATFL and outward rotation of the distal fibula which was kept in this position by means of a wooden wedge placed in the anterior tibiofibular diastasis that was produced He did not however succeed in establishing any demonstrable difference by examinations with or without a wedge Also Bonnin (1950) considers the

roentgenological diagnosis to be difficult and the possibilities of diagnosis by provocation to be small According to his opinion the clinical symptoms must be decisive of the diagnosis Berridge & Bonnin (1944) have shown that the isolated ATFL-rupture is diagnosable by arthrography Brostrom Liljedahl & Lindvall (1965) have described 5 arthrographically diagnosed cases of this injury which also have been operatively explored However they consider the method to be uncertain when more than a week has passed after the occurrence of the injury

4 *Operative examination*

At the operative exploration of stage I injuries one will find a localized hemorrhage around the ruptured ligament and as a rule a rather small and well defined ventrolateral capsule rupture Besides there will be a moderate hemarthrosis Of the 11 patients in the material 1 had a large detached bone fragment involving the whole ATTu (see Fig 8), and 3 had smaller ones In those 7 patients who had their rupture located in the ligament proper, this rupture was situated somewhere in the middle of it (see Fig 9) In the 3 patients who had smaller ATTu fragments these were displaced a few mm in ventral lateral and distal direction The distal part of the fibula in all the 11 patients lay in quite a normal place in relation to the tibia and no form of anterior diastasis could be demonstrated In the purely ligamentous ATFL injuries one of the ligament portions sometimes proved to be trapped in the space between the tibia and the fibula Rupture also of the other lateral ligaments could in no case be demonstrated at the explorations At outward rotation of the foot during the operations one could see how the distal fibula was displaced a few mm in lateral direction at the same time as a diastasis 10—12 mm wide could be produced between the tibia and the anterior margin of the lateral malleolus This diastasis then was possible owing to the fact that the distal fibula could be powerfully rotated around an axis which mainly runs through the interosseous tibiofibular ligament and the interosseous membrane At both outward rotation and dorsiflexion of the foot an increased diastasis arose in the ATFL-rupture which may explain the mechanism behind the indirect ligamentous pain Other movements could not provoke any obvious displacements between the free ends of the ligament The indirect pain which Bonnin and Menelaus could produce by plantar flexion of the foot must probably have reference to the rupture of the joint capsule and consequently cannot be specific to an injury to the ATFL Several authors have made experimental investigations at which they sectioned the ATFL and then measured the size of the anterior tibiofibular diastasis which arose when the foot was rotated outwards Ashhurst (1922) has estimated it at 10 mm Palmer (1941) at 10 Lauge Hansen (1942) at 8 to 9 Hen

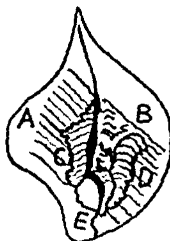


Fig 9 Isolated rupture of the anterior tibiofibular ligament (left ankle) A Tibia B Fibula. C Tibial and D Fibular portion of the ligament F Ventrolateral corner of the trochlea tali and rupture of the joint capsule

delberg (1943) at scarcely 10 and Bonnin (1950) at 4 mm Brostrom (1966) has at operation estimated the size of the diastasis at 5 mm

5 *Differential diagnosis*

The isolated ATFL rupture is above all confused with the isolated ATaFL rupture From an anatomical point of view the ligaments are closely connected with each other see Fig 10 The ATaFL is weaker, and more firmly connected with the joint capsule than the ATFL The ATaFL originates from the ventrodistal part of the lateral malleolus just distally to the

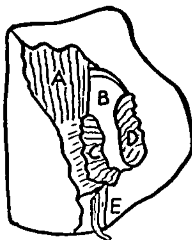


Fig 10 Anatomical relationship between the anterior tibiofibular and anterior talofibular ligaments (right ankle) A. Anterior tibiofibular ligament B Capsule rupture and lateral part of the talus C Fibular and D Talar portion of the ruptured anterior talofibular ligament E Fibular portion of the partially ruptured calcaneofibular ligament

attachment of the ATFL and is attached to the lateral side of the collum tali The ligament easily ruptures when the foot is twisted into powerful supination and inward rotation and more easily when the foot also is put in plantar flexion During the years 1960—1965 94 cases of ATaFL-ruptures have been operated on In 25 to 30 per cent the ligament rupture mentioned was associated with a partial or total CFL-rupture Similar materials have been reported by several authors particularly Brostrom (1966) who found a combined injury to the ligaments mentioned in about 20 per cent Most of the 94 patients have stated pure supination violence to be



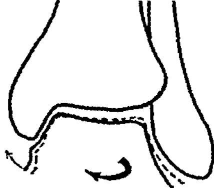
Fig. 11 Rupture of the anterior talofibular ligament of the left ankle. Incongruity in the talofibular joint. Right ankle for comparison in exactly the same projection (20 inward rotation of the foot)



Fig. 12 Same as Fig. 11. In this case there is also a partial rupture of the calcaneofibular ligament

the cause of the injury. They have had rather pronounced swelling and *hematoma ventrally and distally to the lateral malleolus and tenderness on* palpation which has reached its maximum over the actual ligament. Well palpable hemarthroses have seldom been present. Indirect pain could be provoked by forced supination and inward rotation of the foot. At roentgenological examination one has only in a minority of cases found fragments emanating from the distal fibula or the collum tali, thus corresponding to the origin and the attachment of the ligament. At a comparative examination of the intact ankle in exactly the same projection a clear

Fig 13 Talofibular incongruity Mechanism The ruptured talofibular ligament gives rise to ankle instability resulting in slight inward rotation and varus displacement of the talus The arrows indicate the directions of talar movement



incongruity in almost every case has been demonstrable in the joint between the talus and the lateral malleolus, see roentgenograms Figs 11 and 12 This incongruity appearing still more distinctly at a simultaneous CFL-rupture is due to the fact that the ATaFL-rupture gives rise to slight instability in the ankle mortise resulting in rotation of the talus in medial direction and also a slight displacement of it in varus direction see Fig 13

The easiest way to convince oneself that the incongruity is due to this displacement of the talus is to make an operative analysis of a case with an isolated ATaFL-rupture Then one can easily demonstrate the instability as well as the rotation of the talus which the injury can give rise to The same explanation is also given by some experimental investigations in which a total ATaFL rupture has been produced Leonard (1949) who considers the ATaFL to be the most important stabilizing component of the lateral collateral ligament has by cadaver experiments, been able to prove that a section of the ATaFL and the lateral portion of the joint capsule can enable talar tilt in varus direction amounting to 10° when the foot is plantarflexed whereas the ankle is rather stable in the absence of plantar flexion Anderson Lecocq & Lecocq (1952) have made similar examinations and then established instability in both the vertical and the longitudinal axis of the talus with the possibility of tilting up to 6—7°

The difficulty in distinguishing between an isolated ATFL and an isolated ATaFL-rupture by palpation has been emphasized among others by Bonnin (1950) He considers the ATFL to be so sensitive to palpation that at the occurrence of an injury close to this ligament it can localize the maximal point of tenderness to itself During an operative examination of an isolated ATaFL-rupture one will always find an extensive lateral rupture of the joint capsule as a rule stopping at the ATFL It is probably I suppose this rupture of the joint capsule that first of all makes the dif

ferential diagnosis between ATFL and ATaFL-injuries difficult, even to the experienced examiner

The isolated ATaFL rupture can however, be diagnosed by means of other methods namely so-called anteroposterior stability test, so-called stress inversion radiography, and arthrography The first mentioned method is based on experimental examinations performed by Pennal (1943) and Anderson Lecocq & Lecocq (1952) With section of the ATaFL and the lateral portion of the joint capsule, they were able to prove that the foot could be displaced in dorsoventral direction thus producing a ventral subluxation of the talus Anderson Lecocq & Lecocq could also show that increased plantar flexion of the foot was accompanied by increased dorsoventral instability in the ankle When the plantar flexion amounted to 20° they could displace the talus and the foot 7 to 8 mm in ventral direction If the plantar flexion was increased to 35°, they could in addition to the displacement mentioned also show the possibility for the talus to rotate in medial direction Staples (1965) and Coutts & Woodward (1965) have accounted for the clinical application of these observations and shown that an ATaFL-rupture gives rise to anteroposterior instability, which can be roentgenologically registered Staples considers that the examination may be made on fresh ligament ruptures, without anesthesia necessarily being resorted to provided the examination is made as early as possible after the occurrence of the injury Swelling pains and spasm make an examination without anesthesia impossible Coutts & Woodward examine fresh injuries after blocking of the peroneal nerve, which method has been described by Ruth (1961) Broström (1966) has also used the anteroposterior stability test in fresh ligamentous ruptures at which examination has been performed under spinal anesthesia

Stress inversion radiography implies that the ankle is roentgenologically examined in defined projections with the foot inward rotated and the heel adducted The method is best adapted for the diagnosis of combined ATaFL and CFL ruptures even if, as has been shown by Anderson Lecocq & Lecocq (1952) an isolated ATaFL injury can make possible the occurrence of talar tilt in varus direction up to 6—7° The procedure and the practical application of this method of examination, however, have been subjected to much discussion Its clinical value is disputed, and strongly negative opinions about it have been delivered by Rubin & Witten (1960)

Arthrography is stated in the literature to be a reliable method of proving an ATaFL-rupture Methods and roentgenological observations have been described by a number of authors e g Wolff (1940) Hansson (1941) Palmer (1941) Hendelberg (1943) Berridge & Bonnin (1944) Lindblom (1952) Arner Ekengren Hulting & Lindholm (1957), and Rezek (1958) Brostrom Liljedahl & Lindwall (1965) have more systematically employed

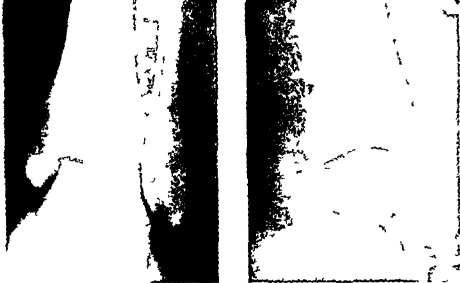


Fig 14 Isolated fracture of the posterior tibial process with rupture of the anterior tibiofibular ligament and vertical fracture of the posterior tibial process

arthrography and published a fairly comprehensive material of ATaFL-injuries

The 3 now mentioned special methods of the establishment of the isolated ATaFL-rupture however have some disadvantages which make them unsuitable for routine clinical work Thus they take up time and require assistance from a qualified staff and medical apparatus

The possibility of proving an ATaFL-rupture by plain radiographs i e the establishment of incongruity in the joint between the talus and the lateral malleolus has not been mentioned in the literature previously The method is simple and is based on the fact that the ankles of each patient are normally symmetric and therefore it requires examination of both the ankles of the patient in exactly the same projections The occurrence of old defectively healed ligamentous ruptures may however reduce the reliability of the method

A second possibility of confusion with the isolated ATFL rupture is what in the literature is mostly termed isolated fracture of the posterior tibial process This injury is characterized by a rupture of the ATFL in combination with an intra articular fracture running vertically and frontally through the posterior part of the distal tibia (see Fig 14) It is mentioned here because as we know it requires quite another treatment than does the isolated ATFL rupture The injury is rare and at the Department of Orthopaedics Lund Hospital it has been diagnosed in only 3 patients

Table 5 Clinical and roentgenological differential diagnosis in ATFL-injuries ATaFL injuries and ATFL-injuries combined with fracture of the posterior tibial process

Ligament injured	Clinical diagnosis	Roentgenological diagnosis	Special methods
ATTI	Moderate hemarthrosis Max swelling and tenderness over the anterior syndesmosis Indirect outward rotation and dorsiflexion pain	Sometimes detached fragment from the ATTu or the lateral malleolus (?)	Arthrography
ATaFL	In most cases slight hemarthrosis Max swelling and tenderness over the talofibular joint Indirect supination and inward rotation pain	Rarely detached fragment from the lateral malleolus or collum tali Incongruity in the joint between the talus and the lateral malleolus	Arthrography Anteroposterior stability test Stress inversion radiography
ATFL + Posterior tibial fracture	The same as in isolated ATFL rupture but often tenderness over the anterior joint capsule too Sometimes swelling and tenderness over the posterior part of the joint	Vertical fracture through the posterior tibial process	(Arthrography)

during the years 1960—1965 Ashhurst & Bromer (1922) found only 1 case among their 300 fractures Hendelberg (1943) has stated a frequency of 5/223 Bistrom (1952) 1/322, and Brostrom Liljedahl & Lindvall (1964) 18/185 fractures Lauge Hansen (1942) and Kristensen (1949) have denied its existence as a special type of injury and want it to be classified among the pronation-outward rotation fractures Palmer (1941) considers the injury to arise by plantar hyperflexion violence causing an anterior rupture of the capsule and a chisel fracture in the tibia By arthrography Hendelberg (1943) showed that the posterior tibial fracture is associated with a rupture of the ATFL and he considers the injury to result from outward rotation violence Bonnin (1950) is of opinion that the injury results from plantar flexion of the foot or powerful dorsal displacement of the latter in neutral position By arthrography, Broström, Liljedahl & Lindvall (1964) have in most of the cases been able to demonstrate an ATFL rupture but no signs indicating a rupture of the anterior capsule They therefore consider that the injury cannot be caused

by plantar hyperflexion but that it deals with an atypical form of SOR injury of stage III instead where the distal oblique fibular fracture for some reason has not occurred

The 3 cases operated on at the Department of Orthopaedics Lund Hospital all had a rupture in the middle of the ATFL and a relatively limited ventrolateral rupture of the capsule At the clinical examination the patients had the same symptomatology that characterizes the isolated ATFL-injury In some case tenderness on palpation over the posterior portion of the joint could be registered The establishment of the posterior tibial fragment has been decisive in forming a diagnosis which has often required several oblique projections at the roentgenological examination as the fractures have shown very slight displacement

Table 5 shows a collation of the diagnostic criteria and methods available for the establishment of ATFL injuries ATaFL-injuries and ATFL injuries in combination with fracture of the posterior tibial process

B Injuries of the anterior tibiofibular ligament occurring in combination with distal oblique fracture of the fibula in stage II, III, and IV

1 *Earlier investigations*

As is clear from Chapter IV the opinions differ widely as to whether or not the distal oblique fibular fracture is combined with a rupture of the ATFL On the basis of experimental as well as roentgenological examinations Lauge Hansen (1942) considers that the ATFL is always ruptured when a distal oblique fracture of the fibula is present and that the ligamentous injury always precedes this fracture He is of opinion that the ligament ruptures with an avulsion fragment from either the ATTu or the lateral malleolus In 2 cadaver experiments Lauge Hansen found that the ATFL was intact in spite of the fibula being fractured in the usual way He ascribed this to the poor quality of the preparation and the forced outward rotation of the foot not occurring as desired and therefore he paid no attention to these observations Lauge Hansen considered that in 60 per cent with certainty and in 22 per cent in all probability he could roentgenologically *show that the ATFL had ruptured* As has previously been mentioned he based this diagnosis on the presence of fragments or contour changes in the ATTu or in the lateral malleolus Magnusson (1944) re-examined 211 cases of SOR fractures and could in 157 (75 %) of them roentgenologically point out signs of injuries to the ATFL in the form of sclerosed and torn off fragments from the ATTu or the lateral malleolus or defects and contour changes in them The injuries included 54 pseud

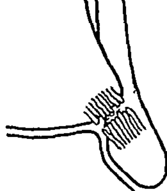
arthroses and 103 contour changes From this Magnusson concluded that all SOR fractures probably have a rupture of the ATFL He writes There is a certain element of probability that all fractures by external rotation involve injury to the anterior tibiofibular ligament Later (1965) he declares that the distal oblique fibular fracture is *always* preceded by a rupture of the ligament mentioned

2 *Different types of rupture and their percentage distribution*

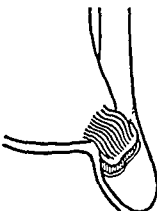
5 main types of ATFL-injuries have been encountered in the present material namely rupture in the ligament itself rupture in the ATTu with or without an avulsion fragment, and rupture in the fibular attachment with or without an avulsion fragment Fig 15 depicts these main types of injuries Here it must be pointed out that combined forms are not uncommon and that the ligament need not in its entirety have connection with the avulsion fragment that has arisen In the material 406 cases with distal oblique fracture of the fibula are included 405 of which have been operated on The remaining case had such severe skin damage that the exploration of the lateral portion of the ankle was avoided Among these 405 cases 389 (96 1 %) were found to have a total ATFL-injury The distribution of the 5 different main types of injuries can be seen in Table 6 From this table it is clear that rupture located in the ligament itself has a very marked predominance and comprises no less than 254 cases (65 3 %) Next come rupture in the fibular attachment and rupture in the ATTu in that order Avulsion fragments could be registered in 88 (22 6 %) cases of which 67 were women and 21 men The material yields much interesting information Especially the great predominance of rupture in the ligament itself is impressive which type of rupture has not been noticed by Lauge Hansen Bonnin (1950) considers that a complete rupture of a ligament in its substance is extremely rare especially in the short ligaments

Table 6 Type distribution of the ATFL-injuries of stage II III and IV in women and men

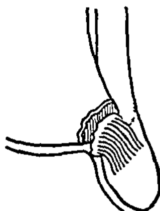
Type of injury	Women	Men	Total	%
A Rupture in the ligament proper	139	115	254	65 3
B Rupture in the fibular insertion	58	18	76	19 5
1 with a bone fragment	40	11	51	
2 without a bone fragment	18	7	25	
C Rupture in the ATTu	41	18	59	15 2
1 with a bone fragment	27	10	37	
2 without a bone fragment	14	8	22	
Total	238	151	389	100 0



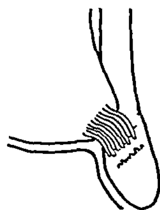
A



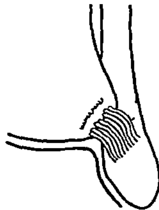
B



C



D



E

Fig 15 Different types of rupture of the anterior tibiofibular ligament occurring in combination with distal oblique fibular fracture arranged in order of frequency Rupture in the ligament proper (A) Rupture in the fibular insertion with (B) and without (D) a bone fragment. Rupture in the tibial origin with (C) and without (E) a bone fragment.

characterizing the ankle Watson Jones (1955) is of the same opinion considering that a ligament even in severe injuries does not rupture in its substance but more commonly in its origin or insertion Weber (1966) considers that the ATFL is seldom injured in its substance Thus these opinions can be completely confuted by the results in this material Also *Broström (1966) has reported that a ligamentous rupture with an avulsion* fragment rarely occurs

VII *Occurrence of uninjured anterior tibiofibular ligament in combination with distal oblique fibular fracture*

In the present material the occurrence of intact ATFL in the presence of distal oblique fracture of the fibula has been registered in 16 cases (3 9 %) In these the fracture has originated just distally to the attachment of the ligament *in the fibula (see Fig 16) The oblique fracture* was in some cases rather short but in the majority of the cases it had an ordinary appearance Among the 16 patients 12 were women and 4 men The distribution into different stages was 6 stage II 2 stage III and 8 stage IV injuries It is difficult to establish the reason why the ATFL had not ruptured in these cases It probably deals with variations in the strength of the bone causing the fracture to appear in the weakest part of the fibula in these cases located in the bone tissue, distally to the attachment of the ligament One can therefore suspect the presence of an osteoporotic fac*tor involved which to a certain degree can have a protective effect on the* ATFL That an osteoporotic factor may be involved is evidenced by 75 per cent of the patients being women and that 75 per cent of them were aged above 40 The 16 cases then prove that the distal oblique fibular frac

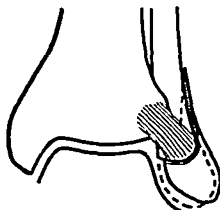


Fig 16 Stage II injury with intact anterior tibiofibular ligament fracture starting below the fibular insertion of the ligament

ture is not necessarily associated with a rupture of the ATFL which circumstance confutes the opinion advocated by Lauge Hansen and Magnusson On the other hand, it is remarkable that so many authors for instance, Ashhurst & Bromer Bishop Bonnin Watson Jones Jergesen Devlies Calvetti Soeur Willenegger, and Weber consider that the ATFL seldom or never ruptures in SOR injuries

VIII *Distal oblique fibular fracture occurring in stage II, III, and IV*

A Different types of fracture Displacement of the distal fibular fragment

406 cases of distal oblique fibular fractures are included in the material 405 of which have been operated on 3 main types of fractures of the fibula have been registered namely 1) a short 2) an ordinary and 3) a long oblique fracture see Fig 17 Among the 406 fractures there was a marked predominance of the ordinary type registered in 349 cases (86 0 %) Next there came the long oblique fracture, registered in 35 cases (8 6 %) The short oblique fracture has been the most uncommon type registered in 22 cases (5 4 %) The fractures have as a rule begun at the level of the joint between the tibia and the talus In a few cases the fracture has begun

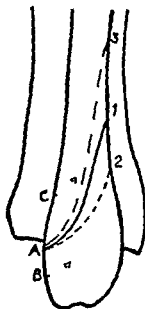


Fig 17 Different types of fibular fracture
A 1 Ordinary type of fracture A 2 Short oblique fracture A 3 Long oblique fracture B Fracture starting below the insertion of the anterior tibiofibular ligament C Fracture above the joint

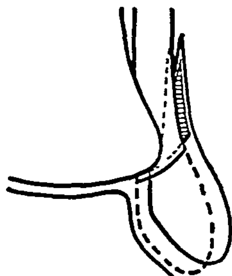


Fig 18 Distal oblique fibular fracture with displacement of the distal fragment in outward rotation and dorsal proximal and lateral direction

somewhat above the joint space and in a few cases below it in the latter the ATFL often being intact The 3 main types of fractures on the whole correspond to those pointed out by Hönigschmied (1877) however, with the exception of his combined transverse and oblique fracture

The distal fibular fragment has as a rule been displaced in outward rotation and in dorsal proximal and lateral direction (see Fig 18) The displacement has, of course been most pronounced in luxation injuries One has not been able to register any great difference between stage II and stage III injuries whereas the injuries of stage IV because of the medial injury component have often promoted the occurrence of lateral displacement with accompanying obvious articular incongruity As to the displacement of the fragment see also Chapter IX C

B The proximal fibular fragment and its relation to the interosseous tibiofibular ligament and the tibia

According to Lauge Hansen (1942), no damage occurs to the interosseous tibiofibular ligament (ITFL) in SOR injuries, and the proximal fibular fragment remains in its normal place in the tibiofibular incisure In the present material however several cases have been registered in which the proximal fibular fragment could be displaced up to 0 5—1 0 cm in lateral direction indicating a distension or a partial rupture of the ITFL The phenomenon has been most frequently observed in stage IV injuries but has also been registered in a few cases of stage II and stage III injuries The same observation has been made by Grath (1964) In some cases of stage IV LUX injuries one has also been able to register complete rup-

ture of the ITFL involving considerable pathological mobility of the proximal fibular fragment Some authors for instance Bosworth (1947) Harris (1947) Fleming & Smith (1954) Fahey Schlenker & Stauffer (1956) and Meyers (1957 1965) have reported SOR injuries in which the proximal fibular fragment has been displaced and fixed behind the posterior tibial tubercle implying that an injury to the ITFL must be present

IX *Injuries of stage II*

A Clinical diagnosis

At the clinical examination the patients have shown considerable swelling round the distal part of the fibula extending over the anterior syndesmosis and often over the whole joint On palpation the patients have complained of considerable tenderness over the oblique fracture in its whole extent but also over the ATFL and the anterior portion of the joint capsule Crepitations corresponding to the fracture have often been registered

B Roentgenological diagnosis

The distal oblique fibular fracture has a very characteristic appearance in the roentgenogram The lateral projection especially is decisive of the



Fig 19 Distal oblique fibular fracture lateral view





Fig. 20 Stage II injury with a typical distal oblique fibular fracture The anterior tibiofibular ligament is ruptured with the avulsion of a fibular fragment which is rotated almost 90° in proximal and tibial direction

diagnosis (see Fig 19) even if, in frontal projections, especially in 20° inward rotation of the foot one can discern the spiral form of the fracture See roentgenograms Fig 20

C Operative examination

Explorative studies of the distal oblique fibular fracture have shown that the distal fracture fragment can present a varying degree of displacement As a rule the distal fibular fragment has been outward rotated and displaced in dorsal and proximal direction involving a shortening in the fracture The fragment has also often been displaced in a lateral direction resulting in a widening of the ankle mortise This widening has made a slight lateral subluxation of the talus possible, in spite of the deltoid ligament being intact see Fig 21 and roentgenograms Fig 22 By experimental investigations Lauge Hansen (1942) Close (1956), and Grath (1960) have shown that the talus can be displaced 2 to 3 mm in lateral direction when the distal part of the fibula has fractured but the deltoid ligament is intact The same observation has been made in the present material

In the literature there are widely diverging opinions about the size of the

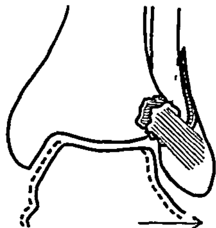


Fig 21 Stage II injury with lateral subluxation of the talus





Fig 22 Stage II injury of the left ankle with an increased distance between the medial malleolus and the talus No injury to the deltoid ligament was found at operation Right ankle for comparison

displacement of the distal fibular fragment Ashhurst & Bromer (1922) consider the distal oblique fibular fracture to be characterized by little or no displacement a conception shared by Bonnin (1950) who moreover considers the fracture to be stable Watson Jones (1955) categorically declares that the fracture does not show any displacement Lauge Hansen (1942) is of opinion that the distal fibular fragment can be displaced up to 30 to 40 outward rotation Picaud (1953) has observed that the distal

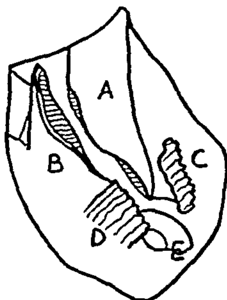


Fig 23 SOR injury with distal oblique fibular fracture (right ankle) A Proximal and B Distal fragment of the fibula C. Tibial and D Fibular portion of the ruptured anterior tibiofibular ligament. E. Capsule rupture and ventrolateral part of the trochlea tali.

fragment is displaced in dorsal and proximal direction and in outward rotation but he has not noticed the lateral displacement Vasli (1957) has not observed any rotation displacement but on the other hand displacement in dorsal as well as lateral direction and also the possibility for the talus to be subluxated in lateral direction Soeur (1961) considers the distal fibular fragment to show only a slight displacement Bohn (1961)

has described all the possibilities of displacement and Cedell & Wiberg (1962) have particularly emphasized the occurrence of shortening and outward rotation

The simultaneous injury to the ATFL and the distal part of the fibula gives rise to very pronounced instability in the ankle especially with regard to the outward rotation of the foot The instability increases owing to the fact that there is also a rupture of the lateral and ventral part of the joint capsule, see operation picture Fig 23 In those cases where the ATFL was intact the instability of the ankle was less pronounced, though however, obvious According to the observations made in the present material an intact ATFL cannot appreciably reduce the instability of rotation but on the other hand better prevent the talus from being subluxated in lateral direction The rupture of the lateral joint capsule accompanying the distal oblique fibular fracture is in its lower part limited by the ATaFL which is always uninjured in SOR injuries

In 13 cases of stage II injuries the deltoid ligament was explored with a view to exclude rupture These patients had slight clinical symptoms on the medial side but the roentgenograms showed an increased distance between the talus and the medial malleolus possibly indicating rupture of the ligament In 1 patient the posterior tibiofibular ligament has also been explored on the suspicion of rupture without one s being able to verify the occurrence of this injury

X *Injuries of stage III*

Patients with a distal oblique fibular fracture and fracture through the posterior tibial tubercle (PTTu) or the posterior tibial process (PTPr) have been grouped in stage III 24 patients have fulfilled these requirements 3 of them have been explored on the medial side in order to exclude rupture of the deltoid ligament

A Clinical diagnosis

The symptomatology of the patients has in no respect been different from that valid for stage II injuries The clinical diagnosis of the posterior tibial fracture has been difficult and the fracture could only exceptionally be established and this due to the patients showing swelling and tenderness on palpation over the posterior part of the joint The same view has been advocated by Hendelberg (1913)




Fig 24 Stage III injury with a large posterior tibial fragment Medial malleolus and deltoid ligament not injured either clinically or at operation

B Roentgenological diagnosis

The roentgenological examination is absolutely necessary for the diagnosis of stage III injuries, at which lateral projections with the foot in at least 85° outward rotation must be used (see Fig 24) Minor fragments and fragments without displacement often require several different projections to be demonstrable From a theoretical point of view the dorsal tibial injury may consist of a ligamentous rupture without an avulsion fragment, an injury which cannot be established by plain radiography and therefore the stage III injuries may suffer a small under representation

C The posterior tibial fragment and its *variations in shape and size*

The posterior fracture of the tibia is generally considered as an avulsion fragment originating from injuries of the posterior tibiofibular ligament (PTFL) and the transverse tibiofibular ligament (TrTFL) Some of the fractures are however considered as chisel fractures caused by the talus Palmer (1941) and before him Grondahl (1913) consider two different types of fractures to exist namely, fracture through the PTTu and fracture through the PTPr the former supposed to have an almost sagittal extension and to affect the articular surface very little and the latter to have

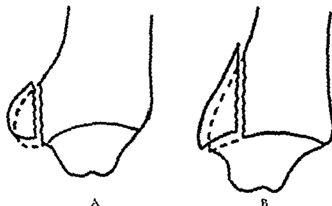


Fig 25 Different types of posterior tibial fracture
A Fracture of the posterior tibial tubercle
B Fracture of the posterior tibial process

a more frontal location and always to be intra articular Lauge Hansen (1954) however considers the dorsal tibial fracture always to be intra articular and the TrTFL first of all to be involved in this injury Accordingly with the support of both experimental and roentgenological examinations he does not believe that there can be an isolated extra articular fracture of the PTTu In the present material two main types of posterior tibial fragments have been registered in appearance agreeing with those reported by Grondahl and Palmer see Fig 25

Lauge Hansen (1942) considers the posterior tibial fracture to arise by the occurrence of 3 different forces namely 1) pressure of the talus on the dorsolateral corner of the tibial articular surface 2) pressure of the distal fibular fragment in dorsomedial direction and 3) pulling of the PTFL and the TrTFL in proximal and dorsal direction Rose (1962) instead believes that the posterior tibial fragment is produced by a direct pressure effect of the medial part of the trochlea tali

The size of the posterior tibial fragments has been measured in roent

Table 7 Classification of the posterior tibial fragments

Group	Definition
Sh	Shell shaped thin bone fragment
1/4	Fragment comprising at most 1/4 of the articular surface
1/3	Fragment comprising more than 1/4 and at most 1/3 of the articular surface
1/2	Fragment comprising more than 1/3 and at most 1/2 of the articular surface

Table 8 Size distribution of the posterior tibial fragments of stage III in women and men

Group	Women	Men	Total
Sh	1	3	4
1/4	7	8	15
1/3	2	1	3
1/2	1	1	2
Total	11	13	24

genograms taken with the foot rotated $\geq 85°$ outward This method of measurement will probably be the only available one and must be considered to be inexact, but still sufficient for an estimation of the mutual size of the fragments In respect to their sizes the fragments have been divided up into 4 groups which broadly speaking are similar to those reported by Hendelberg (1943), see Table 7 Table 8 shows the distribution of the fragments into the different groups from which it is clear that more than 50 per cent of them are included in group 1/4, and that the remaining fragments have a fairly even distribution among the other groups The distribution of sex is even throughout the whole material

XI *Injuries of stage IV*

A Fracture of the medial malleolus

The material includes 238 stage IV injuries comprising 155 women and 83 men *Of these 238 patients 174 (73 1 %) had a fracture through the* medial malleolus 126 were women and 48 men

1 *Clinical diagnosis*

At the clinical examination the patients have shown considerable swelling round the medial malleolus and maximal palpation tenderness over it Crepitations could often be established 3 women had an open fracture *with a transverse wound in the soft parts In 2 women and 1 man, the* posterior part of the medial malleolus was connected with the posterior tibial process in one large fragment

2 *Roentgenological diagnosis*

The medial malleolus has been examined especially in frontal projections The fractures have generally been horizontal and located at the level of the

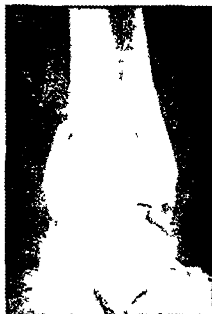



Fig 26 Stage IV injury with an avulsion fragment belonging to the anterior tibio-fibular ligament distal oblique fibular fracture horizontal medial malleolar fracture posterior tibial fracture and dorsal subluxation of the talus

joint space (see Fig 26) *Some of them have been situated more prox imally* and have in that case been of a more oblique type and others have been located at different levels distally to the joint space Very small *malleolar tip fragments have been registered as ruptures of the deltoid* ligament Fissure in the medial malleolus has been registered in scarcely 20 cases

3 *Operative examination*

The malleolar fragment has as a rule been displaced in lateral and ventral direction provided a dorsal subluxation of the talus has not been present in which case the displacement of the fragment has been lateral and dorsal The medial malleolar fracture can allow the talus considerable possibility of subluxation in a lateral direction see Fig 27 The fragment as a rule always accompanies the talus when the latter is displaced in a lateral direc tion *in outward rotation or valgus The malleolar fragment has in many* cases been comminuted Interposition of soft tissue namely fascia peri osteum and ligamentous tissue has to a very high percentage been registered in the medial malleolar fracture This phenomenon has been reported by most of the authors who have explored the medial malleolar fracture Inter position of the posterior tibial tendon reported by some authors for in

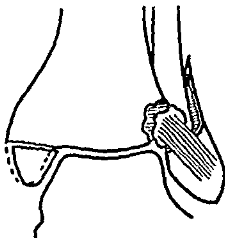


Fig 27 Stage IV injury with fracture of the medial malleolus and lateral subluxation of the talus

stance Lee & Horan (1943) and Coonrad & Bugg (1954) has not been registered The joint capsule has in all the cases turned out to be ruptured in its ventromedial portion the rupture extending from the medial across to the lateral malleolus

B Rupture of the deltoid ligament

Rupture of the deltoid ligament has been registered in 64 cases, i e 26 9 per cent of the 238 patients with stage IV injuries 29 of the patients were women and 35 were men

1 *Clinical diagnosis*

The clinical symptoms of the deltoid rupture do not appreciably differ from those of the medial malleolar fracture Thus the patients have shown swelling of a rather high degree especially below the medial malleolus and considerable palpation tenderness over the ligament With a total ligamentous rupture there has occasionally been a valgus displacement of the foot

2 *Roentgenological diagnosis*

The deltoid rupture can be roentgenologically diagnosed in those cases in which there is an avulsion fragment from the tip of the medial malleolus, and in those cases in which the talus owing to the ligamentous insufficiency has been displaced in valgus position or subluxated in a lateral direction (see Fig 28) In the latter cases the distance between the talus and the medial malleolus should at a comparative examination of the intact ankle have increased more than 2 to 3 mm, see Fig 29 In the great majority of the cases there is no displacement of the talus and therefore the clinical examination must be decisive of the diagnosis even if a rupture of the deltoid ligament may be suspected of being present when the roent

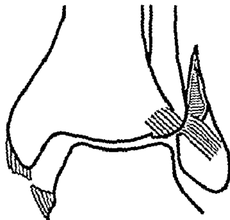


Fig 28 Stage IV injury with rupture of the deltoid ligament and lateral luxation of the talus Fibular portion of the ruptured anterior tibiofibular ligament is trapped in the fibular fracture

genograms show the presence of a considerable swelling of the soft parts around the medial malleolus By plain radiography the distinction of a stage IV injury from a stage III injury and in some cases also from a stage II injury can be very difficult or even impossible This circumstance has been pointed out earlier by Staples (1960) who emphasizes the importance of clinical examination and designates the deltoid rupture the invisible injury He has accounted for a material involving 110 cases of stage IV injuries in which the deltoid rupture has not primarily been diagnosed in 19 cases (17 3 %) Navarre (1962) has also emphasized the importance of the ruptures of the deltoid ligament being diagnosed The deltoid rupture can also be established by arthrography and stress radiography Berridge & Bonnin (1944) and Ciccone & Richman (1948) above all recommend stress radiography at which the ankle is examined with the foot in forced pronation and outward rotation Kleiger (1956) and Staples (1960) also recommend a stability test which they perform in lateral and in both anteroposterior and lateral direction respectively

3 *Operative examination*

Lauge Hansen (1942) considers the deltoid ligament to rupture with a tearing off of a small bone shell from the medial malleolus This type of ligamentous rupture has however only exceptionally been registered in the present material Most of the ligamentous ruptures have instead been located in the ligamentous substance and in its proximal part In not a few cases the rupture has been incomplete with the posterior portion of the deltoid ligament i e mainly the posterior talotibial part remaining intact Observations made may indicate that the tendon of the posterior tibial muscle has a protective effect on this portion of the ligament as the incomplete deltoid ruptures have as a rule stopped at the anterior part of the tendon

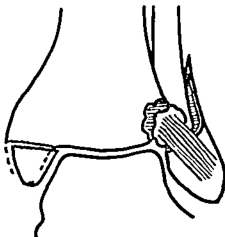


Fig 27 Stage IV injury with fracture of the medial malleolus and lateral subluxation of the talus

stance Lee & Horan (1943) and Coonrad & Bugg (1954) has not been registered The joint capsule has in all the cases turned out to be ruptured in its ventromedial portion, the rupture extending from the medial across to the lateral malleolus

B Rupture of the deltoid ligament

Rupture of the deltoid ligament has been registered in 64 cases i e 26 9 per cent of the 238 patients with stage IV injuries 29 of the patients were women and 35 were men

1 *Clinical diagnosis*

The clinical symptoms of the deltoid rupture do not appreciably differ from those of the medial malleolar fracture Thus the patients have shown swelling of a rather high degree, especially below the medial malleolus, and considerable palpation tenderness over the ligament With a total ligamentous rupture there has occasionally been a valgus displacement of the foot

2 *Roentgenological diagnosis*

The deltoid rupture can be roentgenologically diagnosed in those cases in which there is an avulsion fragment from the tip of the medial malleolus and in those cases in which the talus owing to the ligamentous insufficiency has been displaced in valgus position or subluxated in a lateral direction (see Fig 28) In the latter cases the distance between the talus and the medial malleolus should at a comparative examination of the intact ankle have increased more than 2 to 3 mm see Fig 29 In the great majority of the cases there is no displacement of the talus and therefore the clinical examination must be decisive of the diagnosis even if a rupture of the deltoid ligament may be suspected of being present when the roent

the luxation material than in the whole stage IV material The difference of sex is statistically highly significant The men have shown an even distribution in respect to the presence of luxation injuries in different age groups whereas the women have a maximum in the ages of 40 to 60 see Table 10 72 of the 97 patients were aged at least 40 implying that in round numbers 75 per cent of the luxation injuries occur at the age of 40 or more The mean age in the luxation material is 49.1 ± 16.4 years whereas the mean age of the men is about 2 years higher than that of the women

2 *Clinical diagnosis*

The clinical symptomatology as regards the luxation injuries has been rather uniform At inspection one has been able to register diffuse swelling around the ankle which has been deformed because the talus and the foot have been dislocated in dorsolateral direction By reason of this the foot has been considerably plantarflexed and the heel proximally displaced On palpation the patients have complained of diffuse tenderness over the whole joint and one has been able to register crepitations especially over the lateral malleolus At palpation over the anterior part of the joint one has been able to feel a decided prominence from the distal part of the tibia In cases of fracture through the medial malleolus the proximal tibial fragment has produced a considerable pressure effect on the medial soft parts





Fig 30 Stage IV LUX injury Severe luxation of the talus and the whole foot in dorsal and lateral direction

with signs of nutritive disturbances in them The luxations have sometimes been firmly fixed, in which cases the dorsal dislocation of the talus and the foot has generally been pronounced

3 *Roentgenological diagnosis*

The roentgenological diagnosis has been easy and has as a rule required frontal and lateral projections only In the cases which have been examined with remaining luxation of the talus the joint has as a rule been considerably deranged with dorsal and proximal dislocation of the talus, the posterior tibial fragment, and the malleolar fragments see roentgenograms Fig 30

4 *Correlation to the size of the posterior tibial fragments*

All the luxation injuries have been associated with a posterior tibial fragment varying in size 23 of the 97 luxation injuries (23 7 %) have had a posterior tibial fragment, the size of which has exceeded one fourth of the articular surface From this then it is clear that there is no established connection between luxation of the talus and large posterior tibial fragments Of the 23 patients 17 were women and 6 men which means a clear predominance of women

XII *Injuries of the talus*

The occurrence of injuries to the talus in indirect ankle injuries is considered to be rare Thus Bonnin (1950) considers that the talus as a rule is not damaged in SOR injuries Changes of osteocondritis dissecans originating from injuries to the lateral corner of the trochlea tali, have been reported in the literature by Ray & Coughlin (1947), Nisbet (1954), Roden Tillegard & Unander Scharin (1954), Mau (1959), and Gschwend (1960) They consider that it is exclusively the lateral changes of the talus that have a traumatic etiology Ray & Coughlin, however also describe medial changes of the talus probably arising from trauma Weber (1966) has reported both lateral and medial injuries of the talus which appear in supination injuries and supination outward rotation injuries, respectively In the present work injuries to the talus have only exceptionally been registered which however in some degree may have been due to the fact that it is only during the last few years that one has begun to look for them systematically On the lateral side of the trochlea 2 different types of injuries have been registered namely subchondral fractures affecting the ventrolateral corner of the trochlea and a similar injury to the lateral

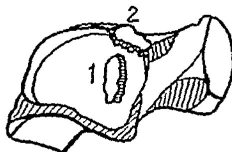


Fig 31 Subchondral fractures of the lateral part of the talus 1 Fragment from the lateral articular surface 2 Fragment from the ventrolateral corner of the trochlea. (For comparison see Fig 32 which shows a similar lesion of the ventromedial corner of the trochlea)

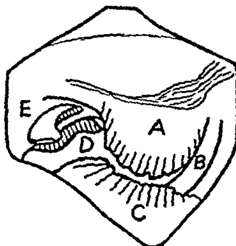


Fig 32 SOR injury with rupture of the deltoid ligament (right ankle) A Medial malleolus and proximal portion of the deltoid ligament. B Tendon of the posterior tibial muscle C Distal portion of the deltoid ligament. D Capsule rupture and ventromedial part of the trochlea tali E Subchondral fracture fragment from the trochlea tali

articular facet, see Fig 31 The subchondral fractures which affected the lateral corner of the trochlea had the same location as described by the above mentioned authors The injuries which affected the lateral articular facet were located in its anterior part and measured about 2×5×10 mm in size The bed of the fragment was always covered with spongy bone This type of injury is probably caused by a pressure effect from the lateral malleolus when the talus is rotated outwards in the ankle mortise On the medial side of the trochlea tali one has registered subchondral fractures of the same type as those affecting the lateral corner Their appearance can be studied in the operation picture, Fig 32 The subchondral fractures have not been visible in the roentgenograms When affecting the corners of the trochlea tali they have mostly been registered in women with stage IV injuries

XIII *Summary*

Clinical, roentgenological and operative examination of 417 supination outward rotation injuries in adult patients has yielded the following information

Supination outward rotation injuries include about 65 per cent of all ankle fractures They are more common in women than in men, the ratio being 1 5 1 In ages above 50 there is a marked predominance of women Approximately the injuries consist of 50 per cent stage IV injuries 40 per cent stage II injuries and 10 per cent stage I and stage III injuries, with a slight predominance of the last mentioned Stage I injuries affect young patients The mean age of the patients is higher in stage II than in stage I and higher in stage IV than in stage II There is on the other hand no statistically significant difference between stage II and stage III, or between stage III and stage IV The higher the patient age, the severer the injury

The stage I injury is rare most of the injuries affecting men, and the rupture of the anterior tibiofibular ligament is usually situated in the ligament itself without an avulsion fragment being present Isolated rupture of the anterior tibiofibular ligament occurs in the frequency of only 10 per cent in a material of purely ligamentous injuries In such a material on the other hand rupture of the anterior talofibular ligament often in combination with the calcaneofibular ligament has a great predominance Isolated rupture of the anterior tibiofibular ligament and isolated rupture of the anterior talofibular ligament can be roentgenologically distinguished as the latter most often shows an incongruity in the joint between the talus and the lateral malleolus

According to this material in 96 per cent of patients distal oblique fibular fractures are combined with total rupture of the anterior tibiofibular ligament which in the majority of the cases is injured in the ligament proper and accordingly without avulsion fragments from the lateral malleolus or the anterior tibial tubercle being present In about 4 per cent distal oblique fibular fractures are not associated with rupture of the anterior tibiofibular ligament the fractures most often originating distally to the attachment of the ligament in the fibula The distal fibular fragment is most often displaced in outward rotation and in dorsal proximal and lateral direction The fracture allows a subluxation of the talus in lateral direction amounting to 2 to 3 mm at the occurrence of an intact deltoid ligament resulting in incongruity in the joint The proximal fibular fragment is generally firmly connected with the tibia but can in partial or total injuries to the interosseous tibiofibular ligament have pathological mobility The joint capsule is generally completely ruptured in its anterior portion

Most of the posterior tibial fragments are small and seldom exceed one fourth of the size of the articular surface which is applicable to stage III as well as stage IV and stage IV with luxation The posterior tibial injury can in stage IV injuries, and probably in stage III injuries as well consist of a ligamentous rupture without the presence of an avulsion fragment Stage IV injuries with intact dorsal structures can appear in which cases the stage IV injury might possibly be caused by an established stage II injury being subjected to secondary pronation violence causing a medial injury but leaving the dorsal structures uninjured In stage IV injuries fracture through the medial malleolus occurs in about 75 per cent and rupture of the deltoid ligament in about 25 per cent In luxation injuries there is a similar distribution Women have a greater predominance of fracture whereas men have a fairly even distribution between fracture and ligamentous rupture Only exceptionally the dorsal tibial fragment can be combined with the dorsal part of the medial malleolus in one large fragment

About 40 per cent of stage IV injuries are complicated by luxation of the talus and the whole foot There is no established correlation between large posterior fragments and luxation of the talus Subchondral fractures of the talus occur at the medial as well as the lateral corner of the trochlea On the lateral side also the articular facet can be the seat of a subchondral fracture which probably arises by pressure from the distal fibula when the talus is rotated outwards in the ankle mortise

Lauge Hansen s stage distribution is on the whole well applicable to the living organism In all probability the posterior tibial injury appears in order before the medial one as except for quite intact medial structures stage III injuries show exactly the same pathologico anatomical changes as

stage IV injuries The most important objection to be raised to Lauge Hansen s work is that he has not, to a sufficient degree, paid attention to the clinical examination of the ankle injuries as a result of which, for instance *stage IV injuries with medial ligamentous rupture have been erroneously* classified as stage II or stage III injuries The operative examination in the present material has also shown divergences from Lauge Hansen s views especially with regard to the frequency and the pathological anatomy of the injuries to the anterior tibiofibular ligament

PART II

Method of operative reconstruction Primary clinical and roentgenological results of treatment

XIV *Earlier methods of treatment*

The literature on ankle injuries and their treatment is very comprehensive Few problems in traumatology would seem to have been subjected to such a great interest and such diverging opinions as the treatment of the ligamentous injuries and fractures of the ankle A study of the literature shows that the different authors agree that the best results of the treatment of ankle injuries are obtained by careful joint reconstruction especially as far as the frequency of arthrosis deformans is concerned As to the methods and means for good joint reconstruction the opinions of the different authors are widely divergent Thus many of them consistently employ conservative treatment implying reduction and fixation in plaster and resort to operation in those cases only where conservative treatment in spite of repeated attempts does not result in acceptable fracture position Some authors consider that some injuries should be primarily operated on such as displaced large posterior tibial fragments displaced medial malleolar fragments and ruptures of the deltoid ligament but in other cases they recommend conservative treatment Other authors again in every injury consistently employ operative treatment with reconstruction of all or almost all the injury components as they consider that conservative treatment does not allow satisfactory joint reconstruction

An advocate of the conservative treatment of ankle injuries is especially L Bohler (1957) who considers that an operation should be performed on defined indications only Other advocates are Lauge Hansen (1942) Kristensen (1949 1956) Bonnin (1950 1965) Portis & Mendelsohn (1953) Fackert (1954) Watson Jones (1955) Jergesen (1959) Kleiger (1961) *Bedogni & Bergami (1962), and Frankel Mc Cue & Humphries (1963)*

Among those pleading for primary operation of injuries to the medial malleolus the deltoid ligament or the posterior tibial process may be mentioned Felsenreich (1936) Andreesen (1938) Muller (1945) McLaughlin & Ryder (1949) Scuderi & Schrey (1950) Sigel (1951) Cox & Laxson

(1952), Torppi (1954), Trojan (1954), Buck Gramcko (1955), Dziob (1956), and Braunstein & Wade (1959)

Advocates of operative treatment are Lane (1912), Lambotte (1912), Picot (1923), Sprengell (1942), Lee & Horan (1943), Burgess (1944) Danis (1949), Hachez Leblanc (1950), Hohmann (1950), Palmer (1950 1962) Desenfans & Evrard (1952), Picaud & Poucel (1952), Reimers (1953), Proctor (1954) Sturzenegger (1954), de Marneffe (1955) Vasli (1957) Devlies (1959) Calvetti (1960), Willenegger (1961), Soeur (1963), Willenegger & Weber (1963) Denham (1964), Goltermann (1964), Burwell & Charnley (1965), Cedell (1965), and Weber (1966) Plaster for external fixation has generally been employed in connection with operative treatment Early mobilization after operation has, however been pleaded for by Muller (1945) Danis (1949) Hachez Leblanc (1950) *Rehn (1953), de Marneffe (1955), Vasli (1957) Willenegger & Weber* (1963) Denham (1964), Burwell & Charnley (1965), and Weber (1966) Treatment in plaster after initial postoperative exercise treatment has been employed by Hachez Leblanc, Vasli and Burwell & Charnley, whereas the other authors have quite given up the treatment in plaster Lance & Wade (1965) report negative experiences of not using plaster

At the operative treatment of the supination outward rotation injuries one has particularly endeavoured to reconstruct the medial and dorsal injury components whereas great importance has not been attached to the lateral one Thus Cox and Lawson (1952) consider that the lateral malleolar fracture never requires operative treatment During the last few years however more and more attention has been paid to the necessity of a careful reconstruction of the distal oblique fibular fracture As early as *1949* Danis advanced the view that the fibular fracture is *the most important* component in an ankle injury, which conception is shared by Picaud (1953) Iselin & de Vellis (1961) and also by Weber (1966), who considers that the medial malleolus may just as well be dispensed with as far as stability is concerned

In order to achieve exact reduction and retention of bone fragments in ankle injuries a multitude of osteosynthesis devices has been suggested for use In the treatment of the distal oblique fibular fracture, one has then made use of cerclage (hemicerclage), plate and screws tibiofibular screw, fibular screw Rush pin intramedullary axial nail and intramedullary axial screw

Good experiences of cerclage have been reported by Lambotte (1912) Picot (1923) Wahlheim (1937) Sprengell (1942), Danis (1949), Rehn (1953) Reimers (1953) Rudberg (1953) Proctor (1954), de Marneffe (1955) Picaud & Poucel (1957) Bergkvist et al (1958), Calvetti (1960) Iselin & de Vellis (1961), Willenegger (1961) Cedell & Wiberg (1962)

Palmer (1962), Soeur (1963), and Cedell (1965) Critical views on using cerclage have especially been expressed by Charnley (1957) and Burwell & Charnley (1965) Sturzenegger (1954) has warned against using cerclage in short oblique fractures

Plate and screws have been used by Lane (1912)

Tibiofibular syndesmosis screw has been used by Lee & Horan (1943) Danis (1949) Palmer (1950) Vasli (1957) Grath (1960) and Klossner (1962) Critical views on screwing of the syndesmosis have been delivered by Bonnin (1950) Sturzenegger (1954) Close (1956) Willenegger (1961) and Weber (1966) who emphasize that it is deleterious to normal joint function

Fibular screw has been used by Burgess (1944) Hachez Leblanc (1950) Desenfans & Evrard (1952) Ewer (1956) Devlies (1959) Jergesen (1959) Navarre (1962) Willenegger & Weber (1963) Burwell & Charnley (1965), Lance & Wade (1965) and Weber (1966)

Rush pin has been used by Hohmann (1950) Braunstein & Wade (1959) Palmer (1962) Dinstl & Spangler (1963) and Wilson & Skilbred (1966) Critical views on using Rush pin have been delivered by Cedell & Wiberg (1962) Willenegger & Weber (1963) Burwell & Charnley (1965) and Lance & Wade (1965)

Intramedullary axial nail has been used by Danis (1949) Sturzenegger (1954) Watson Jones (1955) and Kuntscher (1956)

Intramedullary axial screw has been used by McLaughlin & Ryder (1949), Jergesen (1959) and Denham (1964)

For fixation of posterior tibial fragments screw Kirschner wire and metal pin have been used

Screw has been used by Burgess (1944) Hachez Leblanc (1950) Hohmann (1950) Scuderi & Schrey (1950) Sigel (1951) Reimers (1953) Buck Gramcko (1955) Vasli (1957) Braunstein & Wade (1959) Devlies (1959) Klossner (1962) Palmer (1962) Dinstl & Spangler (1963) Willenegger & Weber (1963) Burwell & Charnley (1965) Cedell (1965) Lance & Wade (1965) and Weber (1966)

Kirschner wire has been used by Felsenreich (1932) Nystrom (1944) and J Bohler (1955)

Metal pin has been used by Hendelberg (1943)

Several authors e g Cadenat (1922) Duval & Basset (1923) Perthes (1924) v Brandis (1939) Danis (1949) Picaud & Poucel (1952) Iselin & de Vellis (1961) Cedell (1965) and Lauttamus & Solonen (1965) have reported that posterior tibial fragments can be exactly repositioned if the distal oblique fibular fracture is fixed in its exact position

Reimers (1953) and Willenegger (1953) warn against osteosynthesis of posterior tibial fragments considering that the operative trauma may in

volve a greater risk to the joint than does a remaining slight displacement

Medial malleolar fractures have been fixed by screw, metal pin Kirschner wire, wire loop and hook plate

Screw has been employed by Andreesen (1938), Burgess (1944), Muller (1945), Hachez Leblanc (1950) Desenfans & Evrard (1952), Fackert (1954) Proctor (1954), Buck Gramcko (1955), Braunstein & Wade (1959) Klossner (1962) Dinstl & Spangler (1963) Willenegger & Weber (1963) Denham (1964) Weber (1966), and Wilson & Skilbred (1966)

Metal pin has been employed by Felsenreich (1936), Wahlheim (1937), Stromberg (1939) Palmer (1941), Hohmann (1950), Vasli (1957), and Cedell (1965)

Kirschner wire has been used among others by J Böhler (1955), and Forgon & Berenyi (1958), the latter using a compression device in combination

Wire loop has been employed by Picot (1923), Felsenreich (1936), Torppi (1954) and Klossner (1962)

Hook plate has been used by Zuelzer (1951) and Picaud (1953)

With regard to their treatment little attention has been paid in the literature to the injuries to the anterior tibiofibular ligament Magnusson (1944) reports that ATFL ruptures with defective healing especially with formation of pseudarthrosis in ATTu fragments give rise to discomfort with pain swelling and tenderness located in the anterior tibiofibular syndesmosis He has also emphasized that an insufficiency in the ATFL gives rise to a persistent widening of the anterior part of the ankle mortise which can allow subluxation movements for the talus in lateral direction resulting in reactive changes in the joint cartilage He considers that he can prove a statistically significant correlation between defectively healed ATFL ruptures and the occurrence of arthrosis deformans Only a few authors treating the distal oblique fibular fracture operatively mention in their works whether the ATFL rupture is subjected to any kind of measure Proctor (1954) mentions suture of the ligamentous rupture concerned Cedell & Wiberg (1962) suggest careful ligamentous reconstruction in stage II injuries and recommend suture and strengthening of the ligament with a special metal staple Palmer (1962) considers it advisable to fix ATTu fragments with pin and to strengthen ATFL-sutures with staple Denham (1964) and Goltermann (1964) report suturing of ATFL ruptures Cedell (1965) recommends careful reconstruction of the ATFL in stage II, III and IV injuries Weber (1966) occasionally fixes large ATTu fragments with a short screw

The isolated ATFL rupture (stage I) has been paid attention to by McLaughlin (1959), who describes nipping of the joint capsule in defec

tively healed ATFL ruptures resulting in discomfort with pain and swelling. He suggests herniorrhaphy. Menelaus (1960) gives an account of 3 instances of ATFL rupture operated on with suture and transsyndesmosis screw. Rose (1962) considers that ATFL rupture in young people should be operated on. Cedell (1965) recommends ligamentous reconstruction with suture and staple. Decoulx et al. (1966) consider an ATFL rupture difficult to suture and therefore stabilize the ligamentous reconstruction with a tibiofibular bolt. Broström (1966) has reported isolated ATFL ruptures which have been sutured.

Among supination outward rotation injuries especially stage III and IV injuries have been subjected to operative treatment. On the other hand one has often been less inclined to operate on stage II injuries as they have been considered to have a very good prognosis by conservative treatment of the simplest kind. Watson Jones (1955) maintains that the stage II injury should be treated conservatively with early mobilization and the simplest fixation possible. He writes about the distal oblique fibular fracture: It is a spiral fracture at the level of the inferior tibiofibular joint but without injury of the ligaments of the joint and without displacement. Bonnin (1965) holds the same opinion and considers that operation involves a great risk and that treatment in plaster will only prolong the duration of the troubles caused by the injury. A different opinion is held by Magnusson (1944) who at follow up examination of stage II injuries found discomfort in 35 out of 118 patients (30 %) and also arthrosis deformans in the same frequency. 11 of these patients suffered from constant and the rest from intermittent discomfort with pain and swelling in the ankle. Treatment of the distal oblique fibular fracture of stage II with walking plaster is recommended by Cox & Laxson (1952) and Soeur (1961). Operative treatment has been recommended by Lee & Horan (1943), Ewer (1956), Picaud & Poucel (1957), Cedell & Wiberg (1962), Cedell (1965) and Lauttamus & Solonen (1965). Cedell & Wiberg have particularly emphasized the risk of arthrosis deformans in cases with remaining incongruity in the joint between the talus and the fibula.

XV *Operative method in the present study*

A General principles

The purpose of the operative treatment is to make a careful reconstruction of ligament and bone injuries in order to eliminate incongruity and dysfunction in the ankle. The lateral injuries have been judged to be obviously

deleterious to normal joint function, and for that reason a great interest has been paid to *the treatment of the ATFL rupture and the distal oblique* fibular fracture The principles of treatment have been a) exploration of the injuries by incisions of optimum length and location, b) employment of an atraumatic technique of operation c) fixation or strengthening of the reconstructed injuries by means of osteosynthesis devices strong lenient to tissue and but little spacious, and d) employment of plaster for external fixation

The distal fibular fracture has been fixed with stainless cerclage wire which has enabled reliable retention of the fracture in the exact position Rupture of the ATFL has been treated with suture or fragment reposition after which the reconstruction of the ligament has been stabilized with a special metal staple the shanks of which have been driven into the bone tissue corresponding to the origin and the attachment of the ligament Large posterior tibial fragments have generally been fixed by screw and medial malleolar fragments usually by metal pin Rupture of the deltoid ligament has been carefully sutured

B Preoperative treatment and time of operation

The ankle injuries have as a rule been treated preoperatively with elastic support and the foot in elevated position Preoperative plaster has in the course of years been more and more seldom used since one has observed that it has often promoted the occurrence of skin damages probably by a combined action of pressure and heat Luxation injuries have as a rule been repositioned immediately on the patient s arrival at the hospital and without preceding roentgenological examination to prevent the occurrence of nutritive skin disturbances Those luxation injuries which for several reasons could not be treated by emergency operation were as a rule treated in preoperative plaster especially cases with unstable fracture position

221 patients (53 0 %) were operated on within 1 day after admission and 132 (31 7 %) within 2 to 3 days Accordingly in round numbers 85 per cent of the patients were operated on within 3 days The remaining patients distribute themselves as follows 39 were operated on within 4 to 7 days 21 within 8 to 14 days 3 within 15 to 21 days and 1 patient after as long as 35 days Causes which necessitated postponement of the opera tions for a longer time were the presence of skin damage indication for cardiovascular function tests the occurrence of other simultaneous bodily injuries with higher priority of treatment, and, conservative treatment having for some time taken place at another hospital within the country or abroad

C Operative anesthesia, approach and technique

As has earlier been mentioned the patients have as a rule been operated on under spinal anesthesia and in a bloodless field Elderly patients and patients with a cardiovascular disease have been operated on under general anesthesia some under local anesthesia A bloodless field has not been employed in elderly patients in patients with a peripheral vascular disease or in patients whose skin has not been in satisfactory condition The lateral side of the ankle has first been explored which procedure has been found to facilitate the reconstruction of the injury components located on this side A curved incision across the distal part of the fibula (see Fig 2) has therefore given good access to the distal oblique fibular fracture the anterior tibiofibular ligament and the ventrolateral part of the joint capsule The fracture has cautiously been freed from clots and mesenchymal tissue and also interpositioned periosteal or ligamentous tissue if any Operative injury to the periosteum has been carefully avoided with a view not to interfere with the healing of the fracture The distal fibular fragment has been repositioned by application of extension ventral displacement and inward rotation to the foot The position obtained has been secured by cerclage round the fracture The cerclage has been found to give good fixation provided the fracture has not been too short or the bone tissue not too osteoporotic in which cases one has had to resort to another form of osteosynthesis usually staple By section of the transverse crural ligament and by medial displacement of the long digital extensor muscle good access to the anterior tibial tubercle was obtained The ATFL could in cases with rupture located in the ligament proper be sutured but in cases with rupture located in its origin or attachment it could only be adapted Ligamentous fragments have been carefully repositioned after which the ligamentous reconstruction has been secured with a metal staple which has also contributed to give very firm fixation of the distal oblique fibular fracture The staple has been inserted with the foot placed in neutral position or in slight dorsiflexion with a view not to produce too tight an ankle mortise making normal dorsiflexion impossible The lateral joint capsule has been sutured After that the medial side of the ankle has been explored through a transverse or vertical incision (see Fig 3) The medial malleolar fracture has cautiously been freed from clots and mesenchymal tissue and also often occurring interposition of fascia periosteum or ligamentous tissue and has then been exactly repositioned at which one has benefited by exposing also the ventral part of the fracture The fragment has been fixed by metal pin exceptionally by screw Ruptures in the different portions of the deltoid ligament have been carefully sutured By displacement of the tendon of the posterior tibial muscle in dorsal and

distal oblique fibular fracture, when the fracture line was short or when the bone tissue was so osteoporotic that cerclage could not be used

The metal pins employed for fixation of the medial malleolar fragment have been Rissler pin and Palmer pin The Rissler pin has in the course of years been abandoned as it has proved to possess some undesirable properties Thus it easily breaks small bone fragments it sometimes slips out and causes a change in the fracture position and it has not such good metallurgical properties The Palmer pin has turned out to be more reliable and has only one weak point, namely, too small a head which can cause penetration of the cortical bone and present difficulties at extraction The

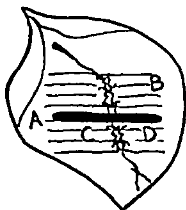


Fig 36 Reconstructed stage I injury (left ankle) The anterior tibiofibular ligament is sutured and strengthened by a syndesmosis staple A Tibia B Fibula C Tibial and D Fibular portion of the ligament (Same patient as Fig 9)

posterior tibial fragments were in the beginning fixed by wing screw but one gradually changed to using a vitallium screw instead Fig 35 shows the 4 types of osteosynthesis devices most often used in the last few years

XVI *Operative treatment of the different stages of supination-outward rotation injuries*

A Isolated rupture of the anterior tibiofibular ligament (stage I)

The purpose of the operation is to prevent the occurrence of an insufficiency in the anterior portion of the syndesmosis 7 patients with rupture in the ligament proper have been operated on by suturing of the ligament and strengthening of it with a staple 4 patients with avulsion fragments from the ATTu have been operated on by reposition of the fragment and fixation of it in 3 cases by staple and 1 case a large fragment by Palmer pin The Figs 36 and 37 show a reconstructed stage I injury where staple has been used



Fig 37 Stage I injury The anterior tibiofibular ligament is reconstructed and strengthened by a syndesmosis staple (Same patient as Fig 6)

B Rupture of the anterior tibiofibular ligament and distal oblique fibular fracture occurring in stage II, III, and IV

The main principle has been exact reduction and fixation of the distal oblique fracture by cerclage The ruptured ATFL has at the same time been reconstructed by suture or fragment reposition, after which a staple has been applied over the ligament thus strengthening it and in addition contributing to the fixation of the fibular fracture (see Fig 38) Short oblique fractures and considerably osteoporotic bone fragments have not been found suitable to be treated by cerclage In these cases, the ligament has been reconstructed in the usual way and strengthened by staple after which the fracture has often been fixed with an additional staple applied over the syndesmosis

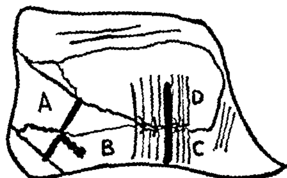


Fig 38 Reconstructed lateral SOR injury (right ankle)
A Proximal and B Distal fibular fragment C Fibular and
D Tibial portion of the sutured anterior tibiofibular ligament
(Same patient as Fig 23)

Table 11 Fixation devices used at the reconstruction of 405 distal oblique fibular fractures

I With syndesmosis staple	329	(81 2 %)
A Cerclage + syndesmosis staple	275	(67 9 %)
1 Cerclage + syndesmosis staple	249	
2 Cerclage + Fibular staple + syndesmosis staple	23	
3 Cerclage + Rush pin + syndesmosis staple	3	
B Different fixation device + syndesmosis staple or syndesmosis staple only	54	(13 3 %
1 Syndesmosis staple ×1	18	
2 Syndesmosis staple ×2	26	
3 Fibular staple + syndesmosis staple	7	
4 Rush pin + syndesmosis staple	2	
5 Rissler pin + syndesmosis staple	1	
II Without syndesmosis staple	76	(18 8 %
A Cerclage	63	(15 6 %)
1 Cerclage	51	
2 Cerclage + fibular staple	9	
3 Cerclage + Palmer pin	3	
B Different fixation device	13	(3 2 %)
1 Fibular staple	13	

405 distal oblique fibular fractures have been treated Table 11 shows how these fractures have been operated on From the table it is clear that 275 fractures (67 9 %) have been operated on with cerclage and syndesmosis staple and that 54 fractures (13 3 %) have been operated on with different fixation device and syndesmosis staple *or* syndesmosis staple only This implies that the syndesmosis staple has been used in a total of 329 cases (81 2 %) The remaining 76 patients have been operated on with osteosynthesis without syndesmosis staple being used 7 patients in whom the ATFL was uninjured belong to this group

C Posterior tibial fragments occurring in stage III and IV

In only 2 of 24 patients with stage III injury the posterior tibial fragment has been operated on with osteosynthesis 1 fragment belonging to group 1/4 was operated on with 1 Rissler pin and 1 belonging to group 1/3 with 2 Palmer pins In 15 of 222 patients (6 8 %) with posterior tibial

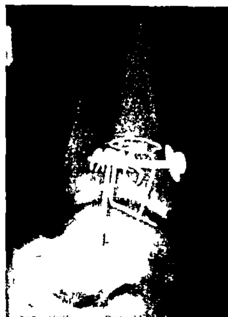



Fig 39 Stage IV injury with a large posterior tibial fragment fixed by wing screw

fracture belonging to stage IV, the fragment was operatively treated (11 women and 4 men) Group ' 1/3 included 6 and group ' 1/2 9 patients *Another 5 cases have been explored for purposes of study in order to find* out the position of the posterior fragment after the distal fibular fracture had been fixed Among the 222 patients only 42 (18 9 %) had a tibial *fragment which involved more than one fourth of the articular surface* Of these patients 15 (35 7 %) were operated on The main principle has been fixation by screw (see Fig 39), which has been employed in 8 cases Of the *remaining patients* 3 were operated on with Rissler pin 1 with staple and 3 with open reduction without fixation

D Fracture of the medial malleolus and rupture of the deltoid ligament (Stage IV)

The main principle in the treatment of medial malleolar fractures has been fixation by metal pin (see Fig 40) 150 out of 174 fractures (86 2 %) were operated on 148 of which with osteosynthesis, and 2 with open re duction without fixation The remaining 24 patients were not operatively treated because of the occurrence of nondisplaced fracture through the malleolus or poor skin vitality in combination with good fragment position Rissler pin has been used in 87 cases Palmer pin in 35, Rissler pin + Pal

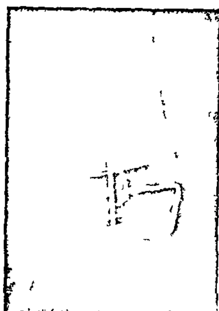



Fig 40 Stage IV injury reconstructed with Palmer pins in the medial malleolar fracture The posterior tibial fragment in the exact position without any special measure of treatment (Same patient as Fig 26

mer pin in 4 Rissler pin + staple in 2 Palmer pin + staple in 3 screw in 12 and staple alone in 5 cases

54 deltoid ruptures out of 64 (84 4 %) were operated on with suture The remaining cases were not operatively treated because of the occurrence of skin damage in combination with a correct position of the talus or small nondisplaced malleolar tip fragments

XVII *Time of immobilization in plaster*

All patients have immediately postoperatively been supplied with a padded lower leg plaster immobilizing the foot in neutral position in respect to dorsoplantar flexion and also to pronation supination Exception has been made for those stage III and IV injuries with posterior tibial fragments in which these fragments have not been treated by osteosynthesis In these cases, the foot has occasionally been immobilized in slight dorsiflexion with a view to try to achieve better retention of the tibial fragment The patients have as a rule not been allowed to weight bear in the plaster during the main part of the time of treatment So called walking plaster has been

Table 12 Differences between the mean times of immobilization in plaster of patients operated on in 1958—1962 and 1963—1965 respectively There are highly significant differences between the two groups in injuries of all stages

Material	Stage	Total	Mean time of immobilization in plaster in weeks
	II	75	7 7 ± 1 8
1958—1962	III	12	9 8 ± 2 1
(208 patients)	IV	121	9 2 ± 1 9
	II	68	5 7 ± 1 3
1963—1965	III	12	6 0 ± 1 3
(194 patients)	IV	114	8 1 ± 1 6

allowed in about 40 to 50 per cent of the cases during the last 2 to 3 weeks of the time of immobilization After completed treatment in plaster the patients have been prescribed elastic bandage, movement and walking exercise, and in cases of edema and discomfort with swelling and pain, treatment with diuretics and antiphlogistics, respectively

Stage I injuries Of the 11 patients operated on 5 have been treated in plaster for 5 weeks 5 in plaster for 6 weeks and 1 in plaster for 7 weeks

Stage II injuries Of 144 patients operated on 1 male patient broke off treatment in the course of time in plaster The mean time of immobilization in plaster for the 143 patients was 6 7 ± 1 9 weeks

Stage III injuries All the 24 patients operated on completed the treatment in plaster The mean time of immobilization in plaster was 7 9 ± 2 5 weeks

Stage IV injuries 235 out of 238 patients completed treatment 1 woman died in the course of treatment in plaster of some other disease 1 woman was an American citizen and continued her treatment in her native country and 1 man was treated at another hospital where, in spite of great efforts his records could not be traced The mean time of immobilization in plaster for the 235 patients was 8 7 ± 1 2 weeks No difference between luxation and nonluxation injuries could be registered

From the above it is clear that the length of time of immobilization in plaster has been directly proportional to the severity of the injuries i e the stage I injuries have had the shortest and the stage IV injuries the longest time of immobilization The length of time in plaster has in the course of years successively become shorter and shorter This tendency has been most noticeable from the year 1963 onwards If the material is divided up into two groups one of which includes patients operated on in the years 1958—1962 and the other including patients operated on in the years

1963—1965 one will find that the mean time of immobilization in plaster has become essentially shorter in the latter group with statistically highly significant difference, see Table 12 The shortening of the time in plaster has according to experiences made not yielded poorer results of healing but has rather facilitated the functional training of the patients

XVIII *Hospital time and sick-leave*

Hospital time

Only 1 of the 417 patients in the material has been operated on as an out patient 195 out of 416 patients (41 7 %) have been treated as inpatients for up to 7 days Of the remaining patients 173 have been treated as in patients for 8 to 14 days and 48 for more than 14 days Long hospital times have been due to multiple injuries the necessity of preoperative skin treat ment or cardiological function test complications of treatment and par ticularly concerning elderly patients socio-medical factors The hospital times have in the course of years successively decreased in length which can be seen in Fig 41 The cause of this is that the postoperative period through the years has had a more favourable course It is possible that also

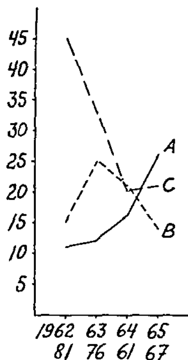


Fig 41 Diagram showing the continuous reduction of hospital times during the years 1962—1965 Curve A ≤5 days curve B 6—7 days and curve C 8—14 days of treatment in hospital The vertical figures stand for numbers of patients the second horizontal line of figures stands for the total amount of supination-outward rotation injuries operated on each year

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Stage I injuries Of the 11 patients operated on 5 have been treated in plaster for 5 weeks 5 in plaster for 6 weeks and 1 in plaster for 7 weeks

Stage II injuries Of 144 patients operated on 1 male patient broke off treatment in the course of time in plaster The mean time of immobilization in plaster for the 143 patients was 6 7 ± 1 9 weeks

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Stage IV injuries 235 out of 238 patients completed treatment 1 woman died in the course of treatment in plaster of some other disease, 1 woman was an American citizen and continued her treatment in her native country, and 1 man was treated at another hospital where in spite of great efforts his records could not be traced The mean time of immobilization in plaster for the 235 patients was 8 7 ± 1 2 weeks No difference between luxation and nonluxation injuries could be registered

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The sick leaves have in the course of years successively become shorter. If those patients operated on in the years 1958—1962 and 1963—196[illegible] respectively are divided up into 2 different groups one will find that the mean sick leaves for the stage II and the stage III injuries have decreased with statistically highly significant and significant difference respectively. For the stage IV injuries again there is no statistically significant difference between the mean sick leave in the two groups see Table [illegible]

XIX *Complications of the operative treatment*

A Survey of the different complications in the present study

The following complications of the operative treatment have been registered

Wound infection 11 patients (2 6 %) 9 patients had mild infections and 2 patients infections of medium severity. Osteitis or osteomyelitis developed in none of them. 3 patients had delayed infection with latent periods up to 6 months after operation. 10 patients had their infection located in the lateral wound and 1 patient had an infection in the lateral as well as the medial wound

Necrosis of the wound edges 9 patients 2 2 [illegible] 1 slight [illegible] instances have been registered the last mentioned with the de[illegible] slowly healing skin ulcers from 1×1 5 to 2×2 [illegible] m in size [illegible] had necrosis in the medial wound 1 patient in the lateral and [illegible] in both wounds

Among the 20 patients who had wound infection or [illegible] wound edges 3 suffered from diabetes, and 1 patient from [illegible] after a cerebral hemorrhage As a rule the patients were advanced in [illegible] and had severe ankle injuries Thus 16 patients had stage IV injuries 8 of which with luxation 1 patient had a stage III injury 2 patients had a stage II injury and one patient a stage I injury

Pressure ulcer from the plaster 3 patients 1 patient had a slight heel necrosis (a woman aged 72 with a stage IV injury) 1 patient had an ulcer 2 5×2 5 cm in size over the dorsal part of the foot (a woman aged 4[illegible] with a stage IV LUX injury) and 1 patient had an ulcer 2[illegible] cm [illegible] size just below the popliteal space (a woman aged 68 with a stage IV injury)

Among other complications the following may be mentioned [illegible] of thrombophlebitis (4 weeks after operation) 2 instances [illegible] thrombosis (3 and 4 weeks respectively after operation [illegible]

pulmonary embolism (4 weeks and 2 months respectively, after operation, both nonfatal), 1 instance of pleurisy (3 days after operation), and 1 instance of AP bleeding (3 weeks after operation treated at another hospital)

B Discussion and comparison with earlier investigations

Several authors have emphasized the risks of complications in surgical treatment of ankle injuries Thus Cave (1965) emphasizes the risks of *sepsis, nonunion malunion circulatory damage nerve injury*, and *soft tissue injury* He warns against operating on patients with diabetes circulatory insufficiency and poor nutritive condition He also warns against spacious osteosynthesis devices Lance & Wade (1965) insist upon restriction when one is going to operate on patients of advanced age, with diabetes markedly impaired circulation or poor condition of the skin Stevens (1964) has made an investigation about the occurrence of postoperative infections at orthopaedic operations and has found that the frequency in different investigations varies between 1 7 and 5 4 per cent His own material comprises 1287 cases 4 35 per cent of which were complicated by infection He considers the occurrence of infections to be promoted by a traumatic technique of operation long times of operation, and an undiscriminating use of antibiotics He does not find any increased frequency of infection in elderly patients or patients with diabetes The frequency of complications varies with different authors Vasli (1957) has reported intra articular infection in 4 cases (2 2 %) superficial necrosis of the wound edges in 36 cases (19 5 %) osteomyelitis in 1 case, thromboembolism in 1 case and peroneal nerve paresis due to pressure of the plaster in 2 cases He employed prophylactic antibiotic therapy in his patients Klossner (1962) reports infection in 8 per cent, of which 1 osteomyelitis in spite of the fact that most of the patients were given prophylactic treatment with antibiotics Burwell & Charnley (1965) have reported the following complications in 135 ankle fractures operated on 8 instances of wound infection (6 %), 2 instances of sepsis 1 vascular injury resulting in amputation, and 2 instances of fatal pulmonary embolism

The frequency of complications in this material must be characterized as very low and the complications as mild All of them have healed and have probably only in a very small degree affected the final outcome even if they have considerably increased the time of treatment They have especially affected elderly patients with severe ankle injuries It is worth noting that no case of established bone infection has been registered in the whole material *The frequency of complication is lower than what has been reported in other investigations*

XX Primary clinical results Classification of the patients

One has been able to estimate the primary clinical result in 413 of the 417 patients operated on The result is defined as equal to the condition of the patient when he can be discharged from treatment and take up work again The primary result of the individual patient is often difficult to estimate and must be based on both the patient s subjective symptoms and the examining surgeon s observations at discharge The primary result is influenced by many factors especially occupation and social status Thus many patients can take up work early in spite of some remaining troubles whereas others must have practically completely recovered from their injury

In respect to the primary clinical result the patients have been divided up into 3 groups namely good medium and poor results

A good result indicates that the patient is symptom free or almost symptom free i e has remaining slight swelling or very slight pain and tiredness only on exertion that the range of motion exceeds 50 per cent of normal and that the capacity for work is normal

A medium result implies persisting moderate swelling pain and tiredness on exertion a range of motion below 50 per cent of normal and on the whole normal capacity for work

A poor result implies persisting severe discomfort of pain swelling and stiffness the occurrence of unilateral limp deformity or flat foot and persisting disability with reduced capacity for work

The classification on the whole agrees with that which Kristensen (1956 employed in his follow up examinations

Table 14 Primary clinical results of injuries of stage II III and IV Correlation to the year of operation.

Stage and groups		58-59	60	61	62	63	64	65	Total
	Good	17	16	13	26	22	21	24	139
II	Medium	—	—	1	2	1	—	—	4
	Poor	—	—	—	—	—	—	—	—
	Good	4	1	1	3	4	3	4	20
III	Medium	—	2	—	—	—	—	—	2
	Poor	—	—	1	—	1	—	—	2
	Good	15	15	35	42	43	31	35	216
IV	Medium	—	4	3	4	2	2	—	15
	Poor	—	1	1	1	—	—	1	[illegible]

pulmonary embolism (4 weeks and 2 months, respectively, after operation, both nonfatal), 1 instance of pleurisy (3 days after operation), and 1 instance of AP bleeding (3 weeks after operation treated at another hospital)

B Discussion and comparison with earlier investigations

Several authors have emphasized the risks of complications in surgical treatment of ankle injuries Thus Cave (1965) emphasizes the risks of sepsis, nonunion malunion circulatory damage, nerve injury and soft tissue injury He warns against operating on patients with diabetes circulatory insufficiency and poor nutritive condition He also warns against spacious osteosynthesis devices Lance & Wade (1965) insist upon restriction when one is going to operate on patients of advanced age with diabetes markedly impaired circulation or poor condition of the skin Stevens (1964) has made an investigation about the occurrence of postoperative infections at orthopaedic operations and has found that the frequency in different investigations varies between 1 7 and 5 4 per cent His own material comprises 1287 cases 4 35 per cent of which were complicated by infection He considers the occurrence of infections to be promoted by a traumatic technique of operation long times of operation and an undiscriminating use of antibiotics He does not find any increased frequency of infection in elderly patients or patients with diabetes The frequency of complications varies with different authors Vasli (1957) has reported intra articular infection in 4 cases (2 2 %), superficial necrosis of the wound edges in 36 cases (19 5 %), osteomyelitis in 1 case, thromboembolism in 1 case and peroneal nerve paresis due to pressure of the plaster in 2 cases He employed prophylactic antibiotic therapy in his patients Klossner (1962) reports infection in 8 per cent of which 1 osteomyelitis in spite of the fact that most of the patients were given prophylactic treatment with antibiotics Burwell & Charnley (1965) have reported the following complications in 135 ankle fractures operated on 8 instances of wound infection (6 %) 2 instances of sepsis 1 vascular injury resulting in amputation and 2 instances of fatal pulmonary embolism

The frequency of complications in this material must be characterized as very low and the complications as mild All of them have healed and have probably only in a very small degree affected the final outcome even if they have considerably increased the time of treatment They have especially affected elderly patients with severe ankle injuries It is worth noting that no case of established bone infection has been registered in the whole material The frequency of complication is lower than what has been reported in other investigations

Table 15 Comparison of the classifications of roentgenologic results of reduction used by Kristensen, Bistrom, Vasli and Klossner

Bone fragment	Group	Kristensen (1949)	Bistrom (1952)	Vasli (1957)	Klossner (1962)
	Good	No lateral displacement Dorsal displacement ≤ 2 mm	No lateral or medial displacement	Dorsal displacement < 2 mm	Dorsal, ventral, proximal or distal displacement ≤ 2 mm
Lateral malleolus	Medium	Lateral displacement ≤ 2 mm Dorsal displacement 2—5 mm	Lateral or medial displacement ≤ 2 mm	Dorsal displacement —5 mm	Dorsal, ventral, proximal or distal displacement 2—5 mm Widening of the mortise < 2 mm
	Poor	Lateral displacement > 2 mm Dorsal displacement > 5 mm	Lateral or medial displacement > 2 mm	Dorsal displacement > 5 mm Lateral displacement	Displacements and widening of the mortise larger than above Rotation, angulation or lateral displacement
	Good	No lateral displacement No angulation Dorsal and ventral displacement and fracture diastasis ≤ 2 mm	No lateral or medial displacement	Dorsal and ventral displacement and fracture diastasis < 2 mm	Dorsal, ventral, proximal or distal displacement ≤ 2 mm
Medial malleolus	Medium	Dorsal and ventral displacement and fracture diastasis 2—5 mm Medial displacement ≤ 2 mm	Lateral or medial displacement ≤ 2 mm	Dorsal and ventral displacement and fracture diastasis 2—5 mm	Dorsal, ventral, proximal or distal displacement 2—5 mm Widening of the mortise < 2 mm
	Poor	Displacements larger than above Lateral displacement Angulation	Lateral or medial displacement > 2 mm	Displacements larger than above Medial and lateral displacement	Displacements and widening of the mortise larger than above Rotation, angulation or lateral displacement
	Good	Fragment > thin shell Displacement ≤ 2 mm	Fragment ≤ 1/4 of the articular surface Displacement [illegible] mm	Fragment > 1/4 of the articular surface Proximal displacement < 2 mm	Fragment ≥ 1/4 of the articular surface Proximal displacement ≤ 2 mm
Posterior tibial margin	Medium	Displacement 2—5 mm	Fragment > 1/4 of the articular surface Displacement ≤ 2 mm	Proximal displacement 2—5 mm	Proximal displacement [illegible] 5 mm
	Poor	Displacement > 5 mm	Fragment > 1/4 of the articular surface Displacement > 2 mm	Proximal displacement > 5 mm	Proximal displacement > 5 mm Displacement of the talus

Table 16 The author's classification of roentgenological results of reduction

Component of injury	Anatomical	Good	Poor
Distal fibular fragment	No displacement	Slight rotation	Lateral and/or dorso-proximal displacement Marked rotation Valgus position
Medial malleolar fragment	No displacement	Slight rotation Dorsal or ventral displacement ≤ 1 mm	Dorsal or ventral dis placement ≥ 1 mm Lateral or medial displacement. Marked rotation Valgus position
Deltoid ligament rupture	No displacement of the talus	No displacement of the talus	Lateral displacement or valgus position of the talus
Posterior tibial fragment	No displacement	Fragment ≤ 1/4 of the articular surface with prox imal and/or dorsal displacement ≤ 2 mm	Fragment ≤ 1/4 of the articular surface with proximal and/or dorsal dis placement > 2 mm Frag ment > 1/4 of the articular surface with proximal *and/or dorsal displacement.*

reduction see Table 16 Anatomical refers to such a result of reduction where in the roentgenograms the talus has a correct position in the mortise, and where all the bone fragments seem to have resumed their original posi tion Small deficiencies in the bone substance due to compression or com *minution in the fractures* have *thereby not been paid regard to Rotational* displacement in the fractures is paid more attention to than in classifica tions earlier published By comparison with exactly adequate projections of the uninjured ankle it has been possible roughly to estimate the size of the rotation of the malleolar fragments Differences in the reproduction of the joints between the talus and the lateral and the medial malleolus of the two ankles have thereby given the information that the malleolar frag ments must have happened to assume a certain rotational displacement Valgus position in fractures has been registered in frontal projections and implies according to the definition a deviation of the distal fracture frag ment in lateral direction in regard to the long axis of the bone If several fracture components are involved in an injury the worst fracture position has determined the group to which the injury is to be referred Displace ments of the talus have always been registered as poor results

C Results

The roentgenological result of treatment has been calculated for all the stage I II III and IV injuries in the material in all 417 patients The whole roentgen material for each patient has been carefully studied and the result of treatment has been estimated on the basis of it The primary roentgenological result for the different stages was

Stage I injuries 11 patients all anatomical Only 4 of the patients had roentgenological changes preoperatively (ATTu fragments The stage I injuries are therefore of very little interest in this connection

Stage II injuries 144 patients 123 anatomical (85 4 %) 17 good (11 8 %) and 4 poor (2 8 %)

Stage III injuries 24 patients 18 anatomical (75 0 % 4 good (16 7 %), and 2 poor (8 3 %)

Stage IV injuries 238 patients 136 anatomical (57 2 % 41 good (17 2 %) and 61 poor (25 6 %)

All stage II III and IV injuries 406 patients 277 anatomical (68 2 %) 62 good (15 3 %) and 67 poor (16 5 %)

If each fracture component is studied separately the following result will be obtained

1 *Distal oblique fibular fracture occurring in stage II III and IV*

a) *Stage II injuries* 144 fractures 123 anatomical 17 good and 4 poor 17 fractures had a slight outward rotation displacement and 4 a slight valgus displacement

b) *Stage III injuries* 24 fractures 20 anatomical 2 good and 2 poor 2 fractures had a slight outward rotation displacement and 2 a slight valgus displacement

c) *Stage IV injuries* 237 fractures (1 fracture not operated on because of the patient s skin damage) 197 anatomical 24 good and 16 poor In the last mentioned group 14 had a valgus displacement and 2 a slight lateral displacement of the distal fracture fragment

In all 405 distal oblique fibular fractures have been operated on The roentgenological result was 340 anatomical" (84 0 %) 43 good (10 6 %) and 22 poor (5 4 %) No pseudarthrosis was registered 1 delayed union occurred (a woman with a stage II injury)

2 *Posterior tibial fracture occurring in stage III and IV*

17 patients have been operated on 14 of whom with osteosynthesis and 3 with open reduction without fixation The size distribution of the fragments was group 1/4 1 patient, group 1/3 7 and group 1/2 9 patients The roentgenological result was 10 anatomical (58 8 %) 1

good (5 9 %) and 6 poor (35 3 %) The 6 'poor results included those 3 tibial fragments repositioned without fixation and 3 tibial fragments involving more than one third of the articular surface which healed with 1 mm proximal displacement If only the 14 cases treated by osteosynthesis are considered, the result is 10 anatomical' (71 4 %), 1 good (7 1 %), and 3 poor (21 5 %)

As has been mentioned earlier, many authors are of opinion that the posterior tibial fragment can generally be repositioned by the distal oblique fibular fracture being fixed in the exact position In consequence of this, it has been of great interest to evaluate the result of treatment for those posterior tibial fractures not operated on In all 229 such cases have been studied 22 of which were stage III injuries and 207 stage IV injuries The roentgenological result was 169 anatomical (73 8 %), 41 good (17 9 %) and 19 poor (8 3 %) From this it is clear that more than 90 per cent of the fractures have obtained a satisfactory position If a similar investigation is made of the tibial fragments involving more than one fourth of the articular surface, i e group 1/3 and group 1/2 the result, however will be different Of a total of 31 such fragments, 11 (35 5 %) will be 'anatomical , 2 (6 5 %) good , and 18 (58 0 %) 'poor , implying that only 42 0 per cent have healed in a satisfactory position If a comparison is made between the posterior tibial fragments operated on with *osteosynthesis and those not operated on* the size of all *involving more than* one fourth of the articular surface one will find the following 9 out of 13 (69 2 %) tibial fragments operated on have obtained an anatomical position while only 11 out of 31 (35 5 %) tibial fragments not operated on have obtained this result The difference between the two groups is statistically significant

3 *Fracture of the medial malleolus and rupture of the deltoid ligament (stage IV)*

150 fractures of the medial malleolus have been operated on, 148 of which with osteosynthesis and 2 with open reduction without fixation The roentgenological result was 119 anatomical (79 3 %) 3 good (2 0 %), and 28 poor (18 7 %) The whole material includes 174 medial malleolar fractures 24 of which have not been operated on because of the occurrence of medial skin damage and nondisplaced fractures Among the 150 fractures operated on 1 pseudarthrosis (0 7 %) has been registered The patient was a man with a fibrous pseudarthrosis causing no discomfort Among the 24 malleolar fractures not operated on 2 pseudarthroses (8 2 %) developed which corresponds to the frequency in other conservatively treated materials (Magnusson 1944 8 1 % Kristensen, 1949 4 7 %, and Bistrom 1952 11 7 %) In this group one has also registered 1 sec

ondary displacement i e a fragment displaced in the course of treatment It was a woman aged 80 who had a displacement of the malleolar fragment in valgus direction Among the 28 patients with poor results there was in 15 a lateral displacement of the medial malleolar fragment (12 patients had a displacement of 1 mm 2 a displacement of 2 mm and 1 a displacement of 3 mm) In 13 patients there was a slight valgus position of the medial malleolar fragment

54 ruptures of the deltoid ligament have been operated on 10 have not been subjected to reconstruction because of the occurrence of skin damage in combination with a correct position of the talus or small non displaced tip fragments from the medial malleolus 2 of the patients operated on recovered with a slight valgus position of the talus indicating ligamentous insufficiency Of the 10 patients not operated on 1 had a valgus displacement of the talus

D Discussion

From what is said above it is clear that in supination outward rotation injuries of stage II III and IV the ankle could be reconstructed anatomically in nearly 70 per cent and satisfactorily in about 15 per cent more The greater the number of the injury components the more difficult it has been to perform the reconstruction Consequently the stage IV injuries could be anatomically reconstructed in scarcely 60 per cent and poor result was obtained in about 25 per cent If the material is grouped according to Kristensen s scheme instead considerably better figures will be obtained namely 346 good (85 2 %) 32 medium (7 9 %) and 28 poor (6 9 %)

The causes of one s not being able to reconstruct the ankle injuries anatomically in more than scarcely 70 per cent can of course be diverse The factors above all playing a role are the surgeon s skill and the choice of method of operation and osteosynthesis devices The first mentioned would seem to have been the most important factor The injuries in the material have been operated on by no less than 18 different surgeons almost all of whom initially had but little experience of the method of operation Besides several of them had not had the opportunity of operating on so many injuries as to obtain a good technique If the patients are divided up into 2 different groups comprising those operated on in the years 19 .. 1962 and 1963—1965 respectively one will find throughout better results of treatment in the last mentioned group see Table 17 It should however be pointed out that the percentage differences are not statistically significant

The choice of osteosynthesis devices does not seem to have affected the





A





B

Fig 42 Woman aged 51 who sustained an ugly stage IV LUX injury in July 1966 (B) By chance she had an ankle roentgen in 1961 when a rheumatoid arthritis was diagnosed (A) The patient was operated on with resulting good joint re construction (C) At follow up examination in February 1967, she was symptom free and the ankle had with the exception of a slight irregularity in the posterior part of the tibia the same roentgenological appearance as before accident (D)





C





D

Table 17 Differences between primary roentgenological results in patients operated on in 1958—1962 and 1963—1965, respectively

Roentgenological results of reduction	1958—1962	1963—1965
Anatomical	138 (65 4 %)	139 (71 3 %)
Good	30 (14 2 %)	32 (16 4 %)
Poor	43 (20 4 %)	24 (12 3 %)
Total	211 (100 0 %)	195 (100 0 %)

results of treatment negatively This view is supported by, among other things the low *frequency of secondary displacement and pseudarthrosis* The cerclage has proved to have no deleterious effect on the healing of the fibular fracture Only one delayed union has been registered In no case the cerclage has fractured in the course of treatment The syndesmosis staple has prevented the occurrence of secondary fibular fracture displacement and also the formation of pseudarthrosis in fragments belonging to the ATFL, nor has fracture of the syndesmosis staple in the course of treatment been registered The Rissler pin has shown some disadvantages and has among other things caused pseudarthrosis in 1 patient by slipping out and causing a diastasis in the malleolar fracture Neither the Palmer pin nor the vitallium screw has had any established deleterious influence on the healing of the fractures

XXII *Correlation between primary clinical results and primary roentgenological results of reduction*

To ascertain whether or not there is any correlation betwen the primary clinical results and the primary roentgenological results of reduction, the good medium , and poor clinical results among the stage II, III and IV injuries in the material have been studied from a roentgenological point of view Of 375 patients with good clinical results 257 (68 5 %) had anatomical 60 (16 0 %) good and 58 (15 5 %) 'poor roentgenological results Of 21 patients with medium clinical results 13 (61 9 %) had anatomical 2 (9 5 %) good' and 6 (28 6 %) 'poor roentgenological results Of 6 patients with poor clinical results 3 (50 0 %) had anatomical and 3 (50 0 %) poor roentgenological results

Of 273 patients with anatomical roentgenological results, 257 (94 1 %)

had "good" 13 (4.8 %) "medium" and 3 (1.1 %) "poor" clinical results. Of 62 patients with "good" roentgenological results 60 (96.8 %) had "good" and 2 (3.2 %) "medium" clinical results. Of 67 patients with "poor" roentgenological results 58 (86.6 %) had "good" 6 (8.9 %) "medium" and 3 (4.5 %) "poor" clinical results.

The best information is given by the distribution of the "poor" roentgenological results into the different clinical groups 58 out of 375 patients (15.5 %) with "good" clinical results 6 out of 21 patients (28.6 %) with "medium" clinical results, and 3 out of 6 patients (50.0 %) with "poor" clinical results thus had "poor" roentgenological results of reduction. The percentage differences are statistically highly significant. There is, therefore in the material an established correlation between the primary clinical results and the primary roentgenological results of reduction.

XXIII *Summary*

Supination-outward rotation injuries have earlier to a great extent been conservatively treated i.e. by reduction and fixation in plaster. In the course of years however the operative treatment has been more and more employed. The literature on ankle injuries and their treatment is very comprehensive and the opinions of the different authors often widely diverge as to therapy. The operative treatment of supination outward rotation injuries has particularly aimed at reconstruction of stage III and IV injuries whereas stage II and especially stage I injuries have been paid little attention to in view of treatment. The literature on the treatment of ruptures of the anterior tibiofibular ligament both those isolated and those combined with distal oblique fibular fractures is very rare. While many authors have shown a great interest in the treatment of the distal oblique fibular fracture they have seldom referred to the rupture of the anterior tibiofibular ligament generally associated with it. The authors who have *recommended operative treatment of supination-outward rotation injuries* have based their conception on the fact that the best results of treatment will be obtained if the joint is reconstructed as completely as possible. They then emphasize that also very slight displacements in fractures and ligamentous injuries can be deleterious to joint function and that good joint reconstruction cannot be obtained by closed methods of treatment.

The treatment of the supination-outward rotation injuries in this material aims at careful operative reconstruction of ligament and bone injuries to prevent the occurrence of incongruity and dysfunction in the ankle. Important principles of treatment have been to use an atraumatic technique

of operation, strong osteosynthesis devices, lenient to tissue and but little spacious, and plaster for external fixation The distal oblique fibular fracture has been fixed by cerclage and a special metal staple the last mentioned at the same time stabilizing the reconstructed anterior tibiofibular ligament Medial malleolar fractures have been fixed with metal pin, and deltoid ruptures have been sutured Large posterior tibial fragments have been fixed by screw The following cases have been operatively treated 11 out of 11 isolated ruptures of the anterior tibiofibular ligament, 405 out of 406 distal oblique fibular fractures, 150 out of 174 medial malleolar fractures 54 out of 64 deltoid ruptures, and 17 out of 246 posterior tibial fractures

The length of time of immobilization in plaster has been directly proportional to the severity of the injury, i e the stage I injuries have had the shortest and the stage IV injuries the longest time of immobilization The mean time of immobilization in plaster has in the course of years been successively reduced for stage II, III and IV

Also the length of the sick leave has been directly proportional to the severity of injuries The mean sick leave has in the course of years been reduced for stage II and III but not for stage IV

The complications of treatment have been few and of fairly mild nature Wound infection has been registered in 2 6 per cent and necrosis of the wound edges in 2 2 per cent Osteitis or osteomyelitis has not occurred The complications have especially affected elderly patients with severe ankle injuries

With regard to the primary clinical result, the patients have been divided up into 3 groups namely good , 'medium , and 'poor' results For 413 patients the primary result was as follows 386 (93 4 %) good , 21 (5 1 %) medium and 6 (1 5 %) 'poor The poor results were found among the stage III and IV injuries

The patients have in respect to the roentgenological result been divided up into 3 groups namely anatomical good and poor results of reduction The author has worked out a stricter classification than any earlier used Special attention has been paid to the occurrence of rotation displacement of malleolar fragments For 406 patients with stage II, III, and IV injuries the primary roentgenological result of reduction was 277 (68 2 %) anatomical 62 (15 3 %) good , and 67 (16 5 %) 'poor Of 405 distal oblique fibular fractures 22 (5 4 %) were 'poor 1 delayed union but no pseudarthrosis was registered Of 150 medial malleolar fractures 28 (18 7 %) were poor Only 1 pseudarthrosis (0 7 %) was registered Of 229 nonoperated posterior tibial fragments only 19 (8 3 %) had unsatisfactory position A closer examination shows that the poor results are applicable to tibial fragments comprising more than one fourth of

the articular surface Large posterior tibial fragments operated on with osteosynthesis had significantly better position than those not operated on The figures indicate that posterior tibial fragments comprising less than one fourth of the articular surface do not require any special operative measure and are given a satisfactory position by the distal oblique fibular fracture being repositioned and fixed There is in the material an established correlation between the primary clinical results and the primary roentgenological results of reduction



PART III

Late clinical and roentgenological results of operative treatment Comparison with late results of non-operative treatment

PART III

Late clinical and roentgenological results of operative treatment Comparison with late results of non-operative treatment

XXIV *Introduction and purpose*

In order to ascertain the late results of the operative treatment of the supination-outward rotation injuries included in the material a follow up examination of the patients operated on in the years 1958—1961 was made An observation time comprising at least 5 years was chosen because the author wanted to find out whether also slight incongruities and fragment displacements in the ankle could result in the development of symptom of insufficiency and arthrosis deformans provided sufficiently long time had elapsed since the injury had healed An important reason was also that the results of the follow up examination were to be compared with those which Magnusson (1944) obtained in his material of conservatively treated fractures where the period of observation totalled 5 to 6 years In the years 1958—1961 a total of 132 patients were operated on In all 100 of them (75 8 %) were subjected to a complete clinical and roentgenological follow up examination Of the remaining 32 patients 7 had died and 4 had moved out of the country or to so distant places in Sweden that one could not expect them to attend the examination 11 patients could not be found because of incomplete addresses 10 patients did not submit to a follow up examination 5 of them because of illness and 5 for lack of time or interest Of the 5 patients who could not attend the follow up examination because of illness 1 stated that he suffered from a serious somatic disease and was mostly confined to bed 2 patients stated pronounced nervous symptoms 1 patient suffered from senile dementia and 1 patient from chronic alcoholism 11 of the 32 patients not followed up were questioned about the condition of their injured ankle by telephone (10 cases) and by letter (1 case) Of the 7 patients who had died, 4 were women and 3 men 2 of them died of complications of diabetes 1 of cerebral hemorrhage 1 by suicide while the others died from causes unknown 5 of these 7 patients were more than 60 years old 1 patient had a stage II injury and 6 patients had stage IV injuries 3 of which were luxation injuries

XXV *Presentation of the follow-up material*

A Distribution of the patients into sex, age, and stage

The sex and age distribution of the patients in the follow up material is shown in Fig 43 The material includes 58 women and 42 men, which means a ratio of 1.4 : 1 The men have a predominance in the age group 25—29 years and the women in the age group 55—59 years The stage distribution can be studied in Table 18, from which it is clear that the material includes 38 stage II injuries (38.0 %), 7 stage III injuries (7.0 %), and 55 stage IV injuries (55.0 %) 21 patients (21.0 %), 14

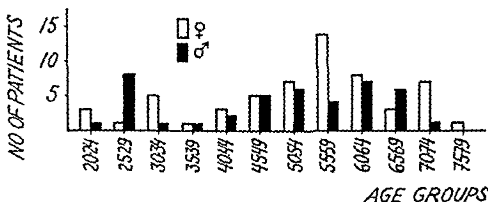


Fig 43 Sex and age distribution of the patients in the follow up material.

Table 18 Distribution of the follow up patients into sex age and stage

Age	Stage II ♀	Stage II ♂	Stage III ♀	Stage III ♂	Stage IV ♀	Stage IV ♂	Total ♀	Total ♂	Total ♀+♂
20—24	2	1	—	—	1	—	3	1	4
25—29	1	3	—	1	—	4	1	8	9
30—34	2	—	—	1	3	—	5	1	6
35—39	1	—	—	—	—	1	1	1	2
40—44	1	1	—	—	2	1	3	2	5
45—49	1	3	—	—	4	2	5	5	10
50—54	2	3	1	—	4	3	7	6	13
55—59	3	1	—	2	11	1	14	4	18
60—64	3	4	—	—	5	3	8	7	15
65—69	1	1	—	1	2	4	3	6	9
70—74	3	1	1	—	3	—	7	1	8
75—79	—	—	—	—	1	—	1	—	1
Total	20	18	2	5	36	19	58	42	100
%	38.0		7.0		55.0		100.0		100.0

women and 7 men had luxation injuries Stage I injuries are not included in the material because no such injuries were registered in the years 1958—1961 The sex distribution is even in stage II whereas the men have a slight predominance in stage III, and the women a marked predominance in stage IV The mean age in stage II is 49 0 ± 15 7 years in stage III 52 3 ± 16 8 years and in stage IV 53 1 ± 13 2 years of which for luxation injuries 57 0 ± 10 5 years The mean age of the whole material is 51 8 ± 14 4 years of which for women 53 5 ± 14 0 years and for men 49 5 ± 14 9 years

B Observation time

The observation time has for no patient been less than 5 years The mean observation time for the whole material is 5 7 ± 0 6 years of which for stage II injuries 5 8 ± 0 7 years for stage III injuries 5 8 ± 0 7 years and for stage IV injuries 5 6 ± 0 6 years

C Comparison with those patients not followed up and with the total material

The sex and stage distribution of the 32 patients not followed up can be studied in Table 19 From this it is clear that the ratio ♀ : ♂ = 2 : 1 and that 31.3 per cent are stage II injuries 6 2 per cent stage III injuries and 62 5 per cent stage IV injuries 9 patients (28 1 %) had luxation injuries The mean age of the patients amounts to 53 3 ± 18 6 years A comparison with the 100 patients subjected to follow up examination one will find that the differences between the two groups with respect to the sex distribution and the mean age of the patients and the degree of severity of the injuries are not statistically significant This implies that the 100 follow up patients well represent all the patients operated on in the years 1958—1961 If the follow up material is compared with the total material of 417 patients one will find an equivalent sex distribution and if the stage I injuries are grouped together with the stage II injuries an almost equal stage distribution (see Table 1) Also the mean age at accident and

Table 19 Sex and stage distribution of 32 patients without follow up examination

Sex	Stage II	Stage III	Stage IV	Total
Women	6	2	13	21
Men	4	—	7	11
Total	10	2	20	32
%	31 3	6 2	62 5	100 0

the frequency of luxation injuries are quite equivalent. The follow up material is accordingly from a statistical point of view representative of the total material, and therefore the results of treatment in the follow up material must be considered to be roughly applicable also to this material However I want to discuss this further in the work

XXVI *Methods of examination*

A Clinical examination

In each patient one has carefully registered subjective symptoms of pain, swelling stiffness tiredness instability or weakness which symptoms have been correlated to the normal activity and to exertions of different kinds The patient s ankle has been subjected to a careful clinical examination at which a comparison with the uninjured ankle has always been made One has studied the patient s walking capacity especially in respect to the normal position and movement of the foot and the presence of a limp One has also registered the presence of edema or local swelling over ligaments or skeletal parts adjacent to the joint and the appearance of the operation scars Ligaments and skeletal parts adjacent to the joint, have been systematically palpated and tenderness, if any has been registered The malleolar size and the calf size have been measured at corresponding points in both legs The presence of flat foot has been registered The strength of the calf muscles has been roughly tested among other things, by asking the patient to walk on his toes One has made a careful measurement of the active and passive range of motion in the talocrural joint as well as in the subtalar joints Exact measurements of pronation and supination have however been difficult to accomplish. The measurements have been performed by means of a goniometer and under standardized conditions

B Roentgenological examination

Both ankles have been examined according to a modification of the method reported by Bolin (1961) i e the same method given an account of earlier in this work One has registered the presence of displacements of the talus malleolar fragments and posterior tibial fragments, pseudarthrosis ligamentous calcification bony bridging in the syndesmosis the condition of the osteosynthesis devices and the occurrence of reactive changes in the osseous tissue caused by them and also arthrosis deformans with reduction of the height of the joint space changes in the subchondral osseous tissue and marginal deposits

XXVII *Classification and presentation of the results of the follow-up examination*

A Subjective results

The patients have with respect to their subjective symptoms been distributed into 3 groups, namely 'good' 'medium' and 'poor' results

A 'good' result denotes that the patient is completely symptom free or has rarely quite negligible symptoms of slight pain swelling stiffness or tiredness and then only after extra exertion

A 'medium' result implies moderate symptoms of pain swelling stiffness or tiredness after exertion but no reduced capacity for work and in most cases normal capacity for exercise and sports

A 'poor' result implies severe symptoms of pain swelling stiffness or tiredness especially on exertion and as a rule reduced capacity for work necessitating a change from heavy to lighter work No or but little sporting activity possible

The distribution of the patients into the different groups can be studied in Table 20 From this it is clear that 88 (88 0 %) patients had 'good' 6 (6 0 %) 'medium' and 6 (6 0 %) 'poor' results Among the 88 patients with 'good' results 47 were women and 41 men The 6 patients with 'medium' results consisted of 5 women and 1 man All the 6 patient with 'poor' results were women There is accordingly a pronounced female predominance in inferior subjective results of treatment

The stage II injuries could be characterized as 'good' results in 36 of 38 cases (94 7 %) the stage III injuries in 6 of 7 cases (85 7 %) and the stage IV injuries in 46 of 55 cases (83 6 %) 'Medium' results occurred in stage II in 1 instance (2 7 %) and in stage IV in 5 instances (9 1 %) 'Poor' results were registered in stage II in 1 instance (2 7 %) in stage III in 1 instance (14 3 %) and in stage IV in 4 instances (7 3 %) Stage IV is accordingly responsible for 9 of the 12 cases (75 0 %) with 'medium' and 'poor' results The patients were completely symptom free

Table 20 Late subjective results in correlation to sex and stage

Subjective results	Stage II ♀	Stage II ♂	Stage III ♀	Stage III ♂	Stage IV ♀	Stage IV ♂	Total ♀	Total ♂	Total ♀ + ♂
Good	18	18	1	5	28	18	47	41	88
Medium	1	—	—	—	4	1	5	1	6
Poor	1	—	1	—	4	—	6	—	6
Total	20	18	2	5	36	19	58	42	100

in 25 of 38 cases (65 7 %) in stage II in 5 of 7 cases (71 4 %) in stage III and in 23 of 55 cases (41 8 %) in stage IV, i e, in 53 0 per cent of the whole material The percentage difference between stage II and stage IV is here statistically almost significant while there is no statistical dif ference between either stage II and III or stage III and IV

24 of the 88 patients (27 3 %) with 'good results were under 45 years of age Among the 6 patients with medium results only 1 patient (16 7 %), a woman, was under 45 years of age Of the 6 female patients with poor results also only 1 patient (16 7 %) was under 45 years of age The percentage difference is not statistically significant

Among the 11 patients questioned about the condition of their ankle by telephone or by letter, 8 stated that they had completely recovered 2 were only slightly and 1 moderately inconvenienced The 10 patients 6 women and 4 men who, therefore could be registered as good results distributed themselves as follows 3 stage II injuries 1 stage III injury, and 6 stage IV injuries 1 of which was a luxation injury The patient with a 'medium result was a woman with a luxation injury Thus in all 111 out of 132 patients (84 1 %) could be judged with regard to their subjective symp toms Of these patients 98 (88 3 %) had 'good 7 (6 3 %) medium , and 6 (5 4 %) poor results

B Objective results

In estimating the objective result one must pay attention to a multitude of factors concerning the appearance and the function of the ankle To classify patients on the basis of a series of observations made at examination can often be difficult and the classification will clearly be somewhat artificial However the patients have again been divided up into 3 groups namely, good medium , and poor results The classification used can be studied in Table 21 For each patient 8 different factors have been sub- jected to special examination The estimation has been strict in so far that the occurrence of *one* poor quality has resulted in the patient s being *classed as a poor result*

The objective results of the 100 follow up patients can be studied in Table 22 from which it is clear that 59 patients (59 0 %) have obtained good results 38 (38 0 %) medium results and 3 (3 0 %) poor results There is among the good results an even sex distribution while the medium results occur twice as often in women as in men The 3 poor results all have reference to female patients

The good results occur in stage II in 31 of 38 patients (81 6 %), in stage III in 4 of 7 patients (57 1 %) and in stage IV in 24 of 55 patients (43 6 %) in which for luxation injuries in 7 of 21 patients (33 3 %)

Table 21 Classification of late objective results
(+) and (−) means increase and decrease respectively

Components	Good	Medium	Poor
Gait	Normal	Normal	Limp
Malleolar size (+)	*0—1 cm*	*1—2 cm*	*> 2 cm*
Calf size (—)	0—1 cm	1—2 cm	> 2 cm
Ligament tenderness	None	Slight	Marked
Dorsoplantar flexion (—)	0—15°	*15—30*	*> 30°*
Pronation supination (—)	0—10°	10—20°	> 20
Pes transverso-planus	None	Slight	Marked
Pes plano-valgus	None	Slight	Marked

Table 22 Late objective results in correlation to sex and stage

Objective results	Stage II ♀	♂	Stage III ♀	♂	Stage IV ♀	♂	Total ♀		Total ♀ – ♂
Good	14	17	1	3	15	9	30	29	59
Medium	6	1	1	2	18	10	25	13	38
Poor	—	—	—	—	3	—	3	—	3
Total	20	18	2	5	36	19	58	42	100

Medium results occur in stage II in 7 instances (18 4 %) in stage III in 3 instances (42 9 %) and in stage IV in 28 instances (50 9 %) in which for luxation injuries in 12 out of 21 patients (57 1 %) The 3 poor results *all pertained to stage IV injuries 2 of which* were luxation injuries The percentage difference between stage II and stage IV is statistically highly significant as regards good results and statistically significant as regards medium results

If the different factors forming the objective results are subjected to a closer study one will find some observations which can be of *interest to* note Slight limp has occurred in 3 patients An increase of the malleolar size of 0 5 to 2 cm has been registered in 66 patients 41 women and 25 men see Table 23 Atrophy of the calf amounting to 0 5 to 2 cm was seen in 36 patients 26 women and 10 men see Table 24 Tenderness on palpation *corresponding to the ATFL* was registered in *9 female patients 2 of* whom with stage II injuries and 7 with stage IV injuries including 3 *luxation* injuries Tenderness on palpation corresponding to the deltoid ligament could be demonstrated in 11 patients 10 women and 1 man who distributed themselves as follows 2 stage II injuries 1 stage III injury and 8 stage IV injuries 5 of which were luxation injuries *50 per cent of the*

Table 23 Increase of malleolar size Correlation to sex

Increase in cm	Women	Men	Total
0 5	9	9	18
1 0	24	10	34
1 5	3	1	4
2 0	5	5	10
Total	41	25	66

Table 24 Decrease of calf size Correlation to sex

Decrease in cm	Women	Men	Total
0 5	7	2	9
1 0	14	6	20
1 5	4	2	6
2 0	1	—	1
Total	26	10	36

Table 25 Decrease of range of dorsoplantar flexion Correlation to stage

Decrease in degrees	Stage II	Stage III	Stage IV	Total
0	24	3	23	50
0—15	14	4	28	46
15—30	—	—	3	3
>30	—	—	1	1
Total	38	7	55	100

patients had a dorsoplantar flexion range corresponding to that of the uninjured ankle and 46 patients had a decrease of this range of motion with 15 degrees at the most see Table 25 46 patients had a pronation supination range completely corresponding to that of the uninjured ankle and 36 patients a decrease of this range of motion with 10 degrees at the most see Table 26 From the table it is clear that the stage IV injuries are responsible for the majority of the great restrictions of motion Unilateral pes transverso planus could be demonstrated in 5 patients 2 of whom women with stage IV injuries and 3 men 1 with a stage II injury and 2 with *luxation injuries On the other hand no case of unilateral pes plano valgus* could be demonstrated among the 100 patients

A comparison between the primary and the late clinical results of the patients might be of certain interest If the follow up results are classi

Table 26 *Decrease of range of pronation supination Correlation to stage*

Decrease in degrees	Stage II	Stage III	Stage IV	Total
0	18	4	24	46
0—10	19	1	16	36
10—°0	1	2	15	18
Total	38	7	55	100

fied in the same way as the primary results one will find that 86 (86 0 %) patients had remained unchanged 5 (5 0 %) were better and 9 (9 0 %) had worse results at the follow up examination Of 91 patients who primarily had good results, 83 (91 2 %) still had 'good results while 7 (7 7 %) had medium results and 1 (1 1 %) a poor result Of 7 patients, who primarily had medium results 1 (14 3 %) still had a medium result while 5 (71 4 %) had good results and 1 (14 3 %) a poor result 2 patients who primarily had poor results still had poor results Those 5 patients, who had improved from medium to good all had stage IV LUX injuries

From the figures it is clear that in the course of years the clinical results of this material have changed to a slight degree only The primary results therefore can give good information about the future function of the injured ankle of the patients

C Roentgenological results

From a roentgenological point of view the follow up patients in conformity with the primary material have been distributed into 3 groups namely anatomical good and poor results The classification is however in some respects different as far as the follow up material is concerned When an ankle injury has healed it is often very difficult to establish and above all measure slight displacements of malleolar fragments Also displacements in posterior tibial fractures can gradually be levelled and thereby be little conspicuous For that reason the classification of late roentgenological results should according to my opinion be stricter than the classification of roentgenological results of reduction as otherwise the follow up results, at a comparison will appear to be too good At the estimation of the late roentgenological results pseudarthrosis and other deviations from the normal healing must also be considered For that reason I have made up a different classification for the follow up results especially with regard to the medial malleolar fracture and the posterior tibial fracture for which at the estimation of the primary results some slight displacements were

Table 27 Classification of late roentgenological results

Component of injury	Anatomical	Good	Poor
Distal fibular fragment	No displacement	Slight rotation	Lateral and/or dorso proximal displacement Marked rotation Valgus position Pseudarthrosis
Medial malleolar fragment	No displacement	Slight rotation	Lateral medial dorsal or ventral displacement Marked rotation Valgus position Pseudarthrosis
Deltoid ligament rupture	No displacement of the talus	No displacement of the talus	Lateral displacement or valgus position of the talus
Posterior tibial fragment	No displacement	Fragment $\leq 1/4$ of the articular surface with proximal displace ment ≤ 1 mm	Fragment $> 1/4$ of the articular surface with proximal displacement Pseudarthrosis

Table 28 Late roentgenological results in correlation to sex and stage

Roentgeno logical results	Stage II ♀	Stage II ♂	Stage III ♀	Stage III ♂	Stage IV ♀	Stage IV ♂	Total ♀	Total ♂	Total ♀+♂
Anatomical	14	18	1	4	21	10	36	32	68
Good	5	—	—	1	7	6	12	7	19
Poor	1	—	1	—	8	3	10	3	13
Total	20	18	2	5	36	19	58	42	100

accepted as good results The classification can be studied in Table 27 For comparison see Classification of roentgenological results of reduction, Table 16

The result of the roentgenological follow up examination can be studied in Table 28 From this it is clear that 68 patients (68 0 %) have ana tomical results 19 (19 0 %) good results and 13 (13 0 %) poor re sults While the sex distribution is even among the good results the women have a slight and a considerable predominance respectively among the medium and the poor results

The stage II injuries could be recorded as anatomical results in 32 of

38 cases (84 2 %), the stage III injuries in 5 of 7 cases (71 4 %) and the stage IV injuries in 31 of 55 cases (56 4 %) Good results occurred in stage II in 5 cases (13 1 %), in stage III in 1 case (14 3 %) and in stage IV in 13 cases (23 6 %) Poor results could be registered in stage II in 1 case (2 6 %), in stage III in 1 case (14 3 %) and in stage IV in 11 cases (20 0 %) Accordingly, 11 of the 13 poor results (84 6 %) pertain to stage IV injuries The percentage difference between stage II and stage IV is for anatomical results statistically significant and for poor results almost significant, whereas the remaining percentage difference are not statistically significant Accordingly the anatomical results are found especially among the stage II injuries, which was also the case with the subjective and the objective good results

There is a good accordance between the follow up material and the total material with regard to the percentage distribution of the different result groups Thus, the total material had anatomical results of reduction in 68 2 per cent good results of reduction in 15 3 per cent and poor results of reduction in 16 5 per cent

In the follow up material no pseudarthrosis could be established Extraction of osteosynthesis devices was carried out in 44 patients distributing themselves among 14 stage II injuries 2 stage III injuries and 28 stage IV injuries 4 out of 20 syndesmosis staples left in position proved to be fractured 1 in the tibial and 3 in the fibular shank Fracture of cerclage metal pin or screw left in position could not be established and nor the presence of reactive changes in the osseous tissue around them neither Bony bridging in the syndesmosis was registered in 3 patients with stage IV injuries 5 patients had calcifications in the syndesmosis 2 with stage II injuries 1 with a stage III injury and 2 with stage IV injuries 4 patients with stage IV injuries had calcifications corresponding to the deltoid ligament 12 patients 5 of whom had been operated on with syndesmosis staple had rather small contour changes in the ATTu or in the anterior margin of the lateral malleolus

XXVIII *Correlation between subjective, objective, and roentgenological results*

A good accordance between the subjective the objective and the roentgenological results in a follow up material including conservatively as well as operatively treated ankle injuries has previously been reported by Kristensen (1949 1956) Bistrom (1952) Vasli (1957) Klossner (1962) Sto-

Table 29 Correlation between late subjective and objective results

	Objective results			
Subjective results	Good	Medium	Poor	Total
Good	59	29	—	88
Medium	—	6	—	6
Poor	—	3	3	6
Total	59	38	3	100

ren (1964), Burwell & Charnley (1965), Weber (1966), and others It has therefore been of interest to investigate whether the same observations could be made in the present follow up material

A Subjective and objective results

The correlation between subjective and objective results can be studied in Table 29 Of 88 patients with good subjective results, 59 (67 1 %) had good objective results while 29 (32 9 %) had medium objective results 6 patients with medium subjective results had also, all of them, medium objective results Of 6 patients with poor' subjective results, 3 had medium and 3 poor objective results

59 patients with 'good objective results had also, all of them, good subjective results Of 38 patients with medium objective results, 29 (76 3 %) had good 6 (15 8 %) medium , and 3 (7 9 %) 'poor subjective results 3 patients with poor objective results had also all of them poor subjective results

From the figures it is clear that there is a very good accordance between the subjective and the objective results in the material

B Subjective and roentgenological results

The correlation between subjective and roentgenological results can be studied in Table 30 From this it is clear that of 88 patients with good subjective results 63 (71 6 %) had anatomical 17 (19 3 %) 'good , and 8 (9 1 %) poor roentgenological results Of 6 patients with 'medium subjective results 3 had anatomical 1 good , and 2 poor roentgenological results Of 6 patients with poor subjective results 2 had 'anatomical , 1 good and 3 poor roentgenological results

Of 68 patients with anatomical roentgenological results, 63 (92 6 %) had good 3 (4 5 %) medium and 2 (2 9 %) poor subjective re

Table 30 Correlation between late subjective and roentgenological results

Subjective results	Roentgenological results			
	Anatomical	Good	Poor	Total
Good	63	17	8	88
Medium	3	1	2	6
Poor	2	1	3	6
Total	68	19	13	100

sults Of 19 patients with good roentgenological results 17 (89 4 %) had good 1 (5 3 %) 'medium and 1 (5 3 %) poor subjective results Of 13 patients with poor' roentgenological results 8 (61 5 %) had 'good, 2 (15 4 %) medium and 3 (23 1 %) 'poor subjective results

The figures indicate that there is a very good accordance also between the subjective and the roentgenological results in the material

C Objective and roentgenological results

The correlation between objective and roentgenological results can be studied in Table 31 Of 59 patients with good objective results 48 (81 4 %) had anatomical 8 (13 5 %) good and 3 (5 1 %) poor roentgenological results Of 38 patients with medium objective results 19 (50 0 %) had anatomical 10 (26 3 %) good and 9 (23 7 %) 'poor roentgenological results Of 3 patients with poor objective results 1 had anatomical 1 good and 1 poor roentgenological result

Of 68 patients with anatomical roentgenological results 48 (70 6 %) had good 19 (27 9 %) medium and 1 (1 5 %) poor objective results Of 19 patients with good roentgenological results 8 (42 1 %) had good 10 (52 6 %) medium and 1 (5 3 %) poor objective result

Table 31 Correlation between late objective and roentgenological results

Objective results	Roentgenological results			
	Anatomical	Good	Poor	Total
Good	48	8	3	59
Medium	19	10	9	38
Poor	1	1	1	3
Total	68	19	13	100

Of 13 patients with 'poor roentgenological results, 3 (23 1 %) had "good 9 (69 2 %) medium and 1 (7 7 %) poor objective results

These is accordingly in the material a good accordance between the objective and the roentgenological results

XXIX *Post-traumatic arthrosis deformans of the ankle*

The frequency of post traumatic arthrosis deformans usually holds an ad vanced position in the estimation of the results of treatment of ankle in juries The frequency as well as the severity of arthrosis deformans varies considerably in different materials because of different selections of patients, different methods of treatment, and different estimations made by different examiners In most cases these factors make a comparison between the re sults of treatment in different clinical materials impossible

In the roentgenograms arthrosis deformans of the ankle is characterized by a reduction of the height of the joint space unevennesses in the articular surface, sclerosis and thinning cysts in the subchondral osseous tissue, and *marginal deposits arising from enchondral ossification*

The pathological anatomy of the post traumatic arthrosis deformans of the ankle has been described by Hohmann (1929), Bergstrand (1944), and others

As regards the etiology of the post traumatic arthrosis deformans of the ankle Beck (1930) emphasized the importance of preventing the occur rence of joint incongruity as it can give rise to a state of irritation resulting in arthrosis deformans Felsenreich (1937) considers mechanical injuries to the joint cartilage nutritive disturbances in the joint cartilage traumat ically based joint incongruities and disturbances in the cerebrospinal and autonomic innervation of the joint to be of importance for the develop *ment of arthrosis deformans He particularly emphasizes the importance* of nonunion in ruptures of the deltoid ligament and fractures of the medial malleolus which results in valgus position of the talus with increased strain on the joint cartilage between the talus and the fibula He also emphasizes that especially elderly people run the risk of sustaining nutritive disturb ances in the joint cartilage Finally he considers step formation in the articular surface of the tibia faulty weight bearing and primary mechanical cartilage injuries to be a common combination of causes of the develop ment of arthrosis deformans after ankle injuries Lewis & Graham (1940) consider loss of the continuity of the weight bearing surface of the tibia widening of the joint mortise and alteration of the weight bearing planes to be the etiology of arthrosis deformans of the ankle Bergstrand (1944)

considers not only cartilage injuries but also functional strain on the injured cartilage to be necessary for the development of arthrosis deformans on the whole. Palmer (1941, 1944) considers arthrosis deformans of the ankle to arise by articular dysfunction, e.g. incongruity between the articular components, faulty weight bearing and changed sliding, after ligamentous injuries. He considers that the ankle as regards function is perhaps the most sensitive joint of the body and that the talus must have the correct position in the mortise after fracture as well as ligamentous injuries at which also slight displacements of fragments and slight widening of the mortise cause incongruities. Magnusson (1944) is of opinion that persisting widening of the anterior tibiofibular syndesmosis occurring in defectively healed ATFL-injuries allows subluxation movements for the talus resulting in reactive articular changes. By cadaver experiments Breitenfelder (1957) has shown that a 2 to 3 mm dorsal displacement of the distal fibular fragment rotates the vertical axis of the talus about 10 degrees outwards, resulting in alteration of the weight bearing planes of the ankle. By similar investigations, Willenegger (1963) has been able to prove that slight displacements of the talus in the mortise, e.g. a 2 mm linear lateral displacement and a displacement of the vertical axis of the talus in 2 to 4 degrees outward rotation, will result in a considerably reduced surface of contact between the tibia and the talus. The increased strain on the joint cartilage in this surface of contact can successively lead to the development of arthrosis deformans.

It has often been emphasized that certain injury components have a more potentially deleterious influence on ankle function than others. Thus Hendelberg (1943) has emphasized the role played by the posterior tibial fragment and considers that large fragments involve a greater risk of arthrosis deformans than small ones. Most of the authors have correlated the occurrence of arthrosis deformans to displacements in fractures through the medial malleolus and the posterior tibial process, while it has generally been considered that there is no correlation between arthrosis deformans and displacements in distal oblique fibular fractures. Thus Kett, Aichner & Wesseli (1965) consider that the lateral malleolar fracture does not require anatomical reduction.

Among the authors who have reported a clear relationship between the roentgenological result of reduction and the frequency of arthrosis deformans may be mentioned Kristensen (1949, 1956), Bistrom (1952), Vasli (1957), Willenegger (1961), Klossner (1962), Navarre (1962), Burwell & Charnley (1965), Willenegger & Weber (1963) and Weber (1966).

Some authors, for instance Cox and Laxson (1952), have emphasized the great importance of initiative injuries for the occurrence of arthrosis deformans of the ankle.

Of 13 patients with 'poor' roentgenological results 3 (23.1 %) had 'good', 9 (69.2 %) 'medium', and 1 (7.7 %) 'poor' objective results

These is accordingly in the material a good accordance between the objective and the roentgenological results

XXIX *Post-traumatic arthrosis deformans of the ankle*

The frequency of post traumatic arthrosis deformans usually holds an advanced position in the estimation of the results of treatment of ankle injuries. The frequency as well as the severity of arthrosis deformans varies considerably in different materials because of different selections of patients, different methods of treatment and different estimations made by different examiners. In most cases these factors make a comparison between the results of treatment in different clinical materials impossible

In the roentgenograms arthrosis deformans of the ankle is characterized by a reduction of the height of the joint space, unevennesses in the articular surface, sclerosis and thinning, cysts in the subchondral osseous tissue and marginal deposits arising from enchondral ossification

The pathological anatomy of the post traumatic arthrosis deformans of the ankle has been described by Hohmann (1929), Bergstrand (1944) and others

As regards the etiology of the post traumatic arthrosis deformans of the ankle, Beck (1930) emphasized the importance of preventing the occurrence of joint incongruity as it can give rise to a state of irritation resulting in arthrosis deformans. Felsenreich (1937) considers mechanical injuries to the joint cartilage, nutritive disturbances in the joint cartilage, traumatically based joint incongruities and disturbances in the cerebrospinal and autonomic innervation of the joint to be of importance for the development of arthrosis deformans. He particularly emphasizes the importance of nonunion in ruptures of the deltoid ligament and fractures of the medial malleolus which results in valgus position of the talus with increased strain on the joint cartilage between the talus and the fibula. He also emphasizes that especially elderly people run the risk of sustaining nutritive disturbances in the joint cartilage. Finally he considers step formation in the articular surface of the tibia, faulty weight bearing and primary mechanical cartilage injuries to be a common combination of causes of the development of arthrosis deformans after ankle injuries. Lewis & Graham (1940) consider loss of the continuity of the weight bearing surface of the tibia, widening of the joint mortise and alteration of the weight bearing planes to be the etiology of arthrosis deformans of the ankle. Bergstrand (1944)

XXX. *Arthrosis deformans occurring in the present follow-up material*

A. Classification

Magnusson's classification (1944) has been used in graduating the changes of arthrosis deformans of the ankle. Thus 4 degrees have been used, namely (+), +, ++, and +++, see Table 32.

B. Frequency and correlation to sex, age and stage

Arthrosis deformans was registered in a total of 23 patients, 17 women and 6 men, implying a predominance of the first mentioned. The changes were moderately pronounced, and the distribution among the 4 different degrees was 13, 8, 1, and 1, respectively. Accordingly, pronounced arthrosis deformans had developed in only 2 patients. Only 2 of the 23 patients (1 woman and 1 man) with arthrosis deformans were under 40 years of age. The mean age of the women was 50.5 ± 7.1 years and that of the men 48.5 ± 14.8 years. The differences of age are not statistically significant. A 55 year old woman with a stage II injury had arthrosis deformans of degree (+), and a 48 year old woman with a stage III injury arthrosis deformans of degree +. The remaining 21 patients had stage IV injuries, 13 of which were luxation injuries. Concerning the sex distribution of these patients and the distribution of the changes of arthrosis deformans in respect to severity, see Table 33.

Thus the frequency of arthrosis deformans for stage II is 1/38 (2.6 %), for stage III 1/7 (14.3 %), for stage IV 8/34 (23.5 %), and for stage IV LUX 13/21 (61.9 %). In stage IV 15 out of 36 women (41.7 %) and 6 out of 19 men (31.6 %) had arthrosis deformans. In stage IV LUX 10

Table 32. Classification of arthrosis deformans according to Magnusson

Degree	Roentgenological changes in the joint
(+)	Slight reduction of the joint space and slight formation of deposits on the joint margins
+	More pronounced changes than mentioned above, possibly with the addition of a sclerotic configuration within the subchondral osseous tissue of the tibia
++	The joint space only about half as high as that of the uninjured side and rather pronounced formation of deposits
+++	The joint space has quite or almost disappeared

Table 33 Degree distribution of arthrosis deformans in women and men in stage IV and stage IV LUX.

Degree of arthrosis deformans	Stage IV ♀	Stage IV ♂	Stage IV LUX ♀	Stage IV LUX ♂	Total ♀	Total ♂
(+)	1	3	7	1	8	4
+	2	—	3	2	5	2
++	1	—	—	—	1	—
+++	1	—	—	—	1	—
Total	5	3	10	3	15	6

out of 14 women (71 4 %) and 3 out of 7 men (42 9 %) had arthrosis deformans There is accordingly, in stage IV a greater percentage fre quency of arthrosis deformans in women but the difference of sex is not statistically significant It has been difficult to determine the time of the beginning of arthrosis deformans In patients with luxation injuries, one has in some cases been able to demonstrate arthrosis deformans roentgeno-logically from 1 1/2 to 2 years after injury

C Correlation to body-weight and occupation

Of the 23 patients with arthrosis deformans 4 women were moderately overweight 2 with arthrosis deformans of degree (+) and 2 of degree + 1 man with arthrosis deformans of degree (+) was considerably over weight In all overweight was proved in only 5 of 23 patients and there fore there is in this material no established correlation between overweight and arthrosis deformans

In order to ascertain whether the patients with arthrosis deformans had averagely heavier work than the other patients, their working conditions were carefully studied Then 5 women turned out to be employed in work requiring much standing and walking and often heavy [illegible] occu pations were shop-assistant bathing woman [illegible]
nurse and gardener The same working conditions were [illegible]
men whose occupations were store man, farmer and [illegible]
8 of 23 patients with arthrosis deformans w[illegible] ed
than that of the average Of the 5 abo[illegible]
had poor subjective results 3 poor [illegible]
roentgenological results which may [illegible] e
of a certain connection between the
ment and also the frequency of arthrosis

XXXI Correlation between subjective results, roentgenological results and arthrosis deformans

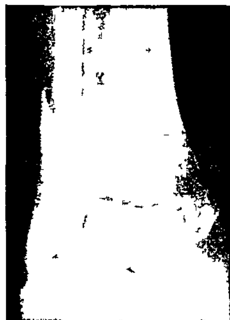
The connection between subjective symptoms and arthrosis deformans and between the roentgenological result of treatment and arthrosis deformans is of great clinical interest. As has previously been mentioned the [illegible] are divergent as to the connection between subjective symptoms and arthrosis deformans, whereas it is generally considered that good roentgenological results are characterized by low frequency of arthrosis deformans. It has for this reason been of interest to investigate whether there [illegible] connection between the components mentioned in this material. [illegible] misunderstanding I want to point out here that the roentgenological result according to its definition only has relevance to the reconstruction of the different injury components and therefore has no reference at all to the occurrence of arthrosis deformans.

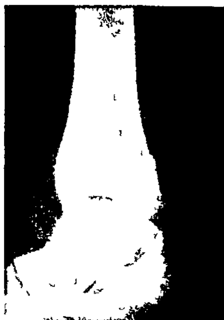
A Subjective results and arthrosis deformans

The correlation between the subjective results in women and men and the degree of arthrosis deformans can be studied in Table 34. 15 of the 23 patients with arthrosis deformans (65.2 %) had good subjective results, 3 (13.1 %) had medium subjective results and 5 (21.7 %) poor subjective results. In view of the whole material arthrosis deformans could be established in 15 out of 88 patients (17.0 %) with good subjective results, in 3 out of 6 patients (50.0 %) with medium subjective results and in 5 out of 6 patients (83.3 %) with poor subjective results. The percentage differences are statistically highly significant and there is there[illegible]

Table 34. Correlation between the subjective results and degree of arthrosis deformans in women and men.

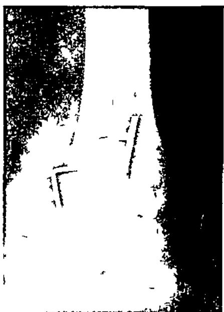
Degree of arthrosis deformans	Subjective results: Good		Medium		Poor		Total	
	n	%	n	%	n	%	n	%
(+)	6	[illegible]	2		1		[illegible]	[illegible]
+	[illegible]	[illegible]	1		[illegible]		[illegible]	[illegible]
++	—				1		1	
+++	—				1		1	
Total	[illegible]	[illegible]	[illegible]		[illegible]		[illegible]	[illegible]





A





B

Fig 44 Woman born in 1889 who sustained a stage IV injury to her right ankle in January 1961 (A) Operated on with ligament reconstruction syndesmosis staple cerclage and Rissler pin (B March 1961) At follow up examination 5 years later she was completely symptom free and had no arthrosis deformans (C March 1966) Left ankle for comparison (D)





C





D

fore, in the material an established correlation between subjective symptoms and arthrosis deformans

B Roentgenological results and arthrosis deformans

The correlation between the roentgenological results and the degree of arthrosis deformans can be studied in Table 35 From this it is clear that 9 of the 23 patients with arthrosis deformans (39 2 %) had 'anatomical', 7 (30 4 %) good and 7 (30 4 %) poor' roentgenological results In view of the whole material arthrosis deformans could be established in 9 out of 68 patients (13 2 %) with anatomical results in 7 out of 19 patients (36 8 %) with 'good results and in 7 out of 13 patients (53 8 %) with poor results The percentage differences are also here statistically *highly significant There is therefore in the material* an established correlation between the roentgenological result and arthrosis deformans

In order to ascertain whether posterior tibial fragments which had healed with persistent displacement could be supposed to be of importance for the development of arthrosis deformans the *primary roentgenological* result of all the stage IV injuries in the follow up material was studied One then found that 6 of the 55 patients had no posterior fragment and that 1 of these 6 patients had arthrosis deformans Accordingly, 49 patients 20 of whom with arthrosis deformans could be studied In 15 of these 49 patients the posterior tibial fragment had healed with remaining proximal displacement *amounting to 1 to 2 mm Of these 15 patients 10 (66 7 %)* turned out to have arthrosis deformans Among the 34 patients in whom the posterior fragment had healed without displacement 10 were also found to have arthrosis deformans, which corresponds to 29 1 per cent The percentage difference between the two groups 37 6 per cent is statistically almost significant implying that displaced posterior fragments are more often accompanied by arthrosis deformans than are nondisplaced ones

Tabl 35 Correlation between late roentgenological results and degree of *arthrosis deformans.*

Degree of arthrosis deformans	Roentgenological results			
	Anatomical	Good	Poor	Total
(+)	5	4	4	13
+	2	3	3	8
++	1	—	—	1
+++	1	—	—	1
Total	9	7	7	23

In order to investigate what importance the size of the posterior tibial fragments could have for the development of arthrosis deformans the e fragments were divided up into 2 groups comprising $\leq 1/4$ and $> 1/4$ of the articular surface respectively One then found that 4 out of 15 patients (26 7 %) with large displaced posterior fragments had arthrosis deformans while only 3 out of 34 patients (8 8 %) with large nondisplaced fragments had arthrosis deformans A similar division of the small fragments was made at which 6 out of 15 patients (40 4 %) with displaced fragments and 7 out of 34 patients (20 6 %) with nondisplaced fragments were found to have arthrosis deformans This implies that patients with large displaced posterior fragments have arthrosis deformans 3 times as often as patients with large nondisplaced fragments, and that patients with small displaced posterior fragments have arthrosis deformans twice as often as patients with small nondisplaced fragments Because of the small size of the material the percentage differences are, however, not statistically significant

XXXII *Comparison of subjective results, roentgenological results and frequency of arthrosis deformans in patients operated on with and without the use of the syndesmosis staple*

As has previously been mentioned in Part II all the patients in the present material have not been operated on with syndesmosis staple In the follow up material patients operated on with syndesmosis staple and patients operated on without syndesmosis staple happened to be almost equal in number namely 49 and 51 respectively For this reason an investigation was made to ascertain whether the staple could be supposed to have any favourable or unfavourable effect on the subjective and the roentgenological results of the patients and on the occurrence of arthrosis deformans

The staple material included 30 women and 19 men distributing them selves among 13 stage II injuries 4 stage III injuries and 32 stage IV in juries 11 of which were luxation injuries The nonstaple material in cluded 28 women and 23 men distributing themselves among 25 stage II injuries 3 stage III injuries and 23 stage IV injuries 10 of which luxa tion injuries ' The staple material accordingly, with regard to percentage includes more female patients and more stage IV injuries than the non staple material The mean age in the staple material is also about 3 5 years higher than that in the nonstaple material whereas the mean ob servation time is 5 to 6 months longer in the last mentioned material

Table 36 Late roentgenological results in 49 patients operated on with the use of the syndesmosis staple Correlation to sex and stage

Roentgenological results	Stage II		Stage III		Stage IV		Total	
	♀	♂	♀	♂	♀	♂	♀	♂
Anatomical	6	5	1	3	14	8	21	16
Good	1	—	—	—	2	2	3	2
Poor	1	—	—	—	5	1	6	1
Total	8	5	1	3	21	11	30	19

Table 37 *Late roentgenological results in 51 patients operated on without the use of the syndesmosis staple. Correlation to sex and stage*

Roentgenological results	Stage II		Stage III		Stage IV		Total	
	♀	♂	♀	♂	♀	♂	♀	♂
Anatomical	8	13	—	1	7	2	15	16
Good	4	—	—	1	5	4	9	5
Poor	—	—	1	—	3	2	4	2
Total	12	13	1	2	15	8	28	23

At a comparison between the subjective results of the two materials, one will find no established difference Thus the distribution of 'medium' and 'poor' subjective results was 5 in 'the staple material' and 7 in 'the non staple material', respectively

The roentgenological result of the patients in 'the staple material' can be studied in Table 36 from which it is clear that of 49 patients 37 (75 5 %) had 'anatomical' 5 (10 2 %) 'good' and 7 (14 3 %) 'poor' results The roentgenological result of the patients in 'the nonstaple material' can be studied in Table 37, from which it is clear that the corresponding figures are 60 8 % 27 4 % and 11 8 % The greatest difference between the materials is to be found in stage IV where 'anatomical' results in 'the staple material' amounted to 68 8 % compared to 39 1 % in 'the nonstaple material'

Arthrosis deformans was observed in 12 patients in 'the staple material' 1 with a stage II injury and 11 with stage IV injuries, and in 11 patients in 'the nonstaple material' 1 with a stage III injury and 10 with stage IV injuries The stage IV injuries in 'the staple material' had arthrosis deformans in 11 out of 32 cases (34 4 %) and in 'the nonstaple material'

in 10 out of 23 cases (43 5 %) Among 20 patients with their staple still left in position, only 1 was found to have arthrosis deformans It was a woman with a stage IV injury who had an arthrosis deformans of degree +

Summarily it can be said that patients in stage IV operated on with syndesmosis staple with regard to percentage have a higher frequency of anatomical reconstructions and a lower frequency of arthrosis deformans than patients in this stage operated on without syndesmosis staple The difference is with regard to the roentgenological result statistically almost significant The results indicate clearly that the syndesmosis staple enables a more exact joint reconstruction and that it has no deleterious effect on the ankle even in those cases where it is left in position

XXXIII *Comparison of the late results of conservative treatment with those of the present follow up material*

A Short survey of Magnusson's material of nonoperated supination outward rotation fractures

1 *Distribution of the patients into sex age and stage*

In his dissertation Magnusson (1944) gave an account of a material of conservatively treated supination outward rotation fractures including 386 patients of whom 183 were women and 203 men Of these patients 211 (54 6 %) were followed up 102 were women and 109 men The mean age of the patients was 47 5 ± 1 0 years of which for women 49 8 ± 1 6 years and for men 45 5 ± 1 5 years The mean observation time was about 6 1 years of which for women 5 4 and for men 6 9 years The stage distribution was roentgenologically based and comprised 5 different groups of fractures namely unimalleolar fractures" unimalleolar fractures with fracture of the posterior tibial margin bimalleolar fractures bimalleolar fractures with fracture of the posterior tibial margin and fractures with luxation of the ankle joint The groups comprised 118 29 20 33 and 11 patients respectively If the patients are re grouped into the different stages used in the present material, stage II will comprise 118 (55 9 %) stage III 29 (13 8 %) and stage IV 64 patients (30 3 %) This re grouping can only be approximate as Magnusson s unimalleolar fractures and ' unimalleolar fractures with fracture of the posterior tibial margin comprise an unknown number of cases with rupture of the deltoid ligament Because of this stage II and III in Magnusson s material will be somewhat over represented at the expense of stage IV

2 *Method of treatment Immobilization and treatment times*

The conservative treatment of fractures in Magnusson s material implied reduction with inward rotation of the foot and fixation by padded or un padded plaster The mean time of immobilization in plaster varied between 27 4 ± 1 3 days (stage II injuries) and 44 2 ± 2 2 days (stage IV injuries) The mean treatment time varied between 51 1 ± 2 5 days (stage II injuries) and 91 8 ± 8 7 days (stage IV injuries)

3 *Comparison of Magnusson s material with the present follow up material*

The differences between Magnusson s follow up material and the present follow up material with respect to the number of patients, their sex and stage distribution mean age, mean times of observation, and mean times of immobilization in plaster can be studied in Table 38 From this it is clear that there is an even sex distribution in Magnusson s material whereas the women have a clear predominance in the present material His material has a predominance of stage II injuries, whereas the present material has a predominance of stage IV injuries The percentage differences for the stage II and the stage IV injuries are statistically significant The mean time of observation in the two materials is almost equivalent The mean time of immobilization in plaster in Magnusson s material is shorter than that in

Table 38 Comparison of Magnusson s follow up material with the present follow up material

Factors	Magnusson s material	Present material
Number of patients	211	100
Ratio ♀ ♂	102 109 = 1 1 1	58 42 = 1 4 1
Stage II	118 (55 9 %)	38 (38 0 %)
Stage III	29 (13 8 %)	7 (7 0 %)
Stage IV	53 (25 1 %)	34 (34 0 %)
Stage IV LUX	11 (5 2 %)	21 (21 0 %)
Mean age at follow up examination	47 5 ± 1 0 years	51 8 ± 14 4 years
Mean observation time	About 6 1 years	5 7 ± 0 6 years
Mean time of im mobilization in plaster		
Stage II	27 4 ± 1 3 days	54 6 ± 9 8 days
Stage III	42 5 ± 16 1 days	63 7 ± 16 1 days
Stage IV	44 2 ± 2 2 days	63 0 ± 13 3 days
Stage IV LUX	51 1 ± 3 2 days	65 1 ± 15 4 days

the present material. It should also be observed that the patients in Magnusson's material have been allowed to weight bear in the plaster earlier than those in the present material, and that the time of treatment in his material cannot be compared with the sick leave in the present follow-up material, as the terms would seem to have a different meaning.

B. Differences between the late results of Magnusson's material and those of the present follow-up material

1. *Late subjective and objective results*

In his follow-up material Magnusson has no strict classification of the subjective results. He uses the word "discomfort" as a common term for "pain, tiredness, weakness or insecurity in the ankle joint". The discomfort of the patients is stated to be "constant or intermittent", in the latter case the discomfort appearing "after exertion, unaccustomed movements and the like". Nor does Magnusson, as far as the objective symptoms are concerned, use any particular strict classification and, in conformity with his estimation of the subjective symptoms, he does not use any distribution into, for instance, "good", "medium" or "poor" results. It is therefore not easy to make a comparison between the results in Magnusson's material and those in the present material. It has, however, been possible for the author to recalculate the results in the present follow-up material so as to be applicable

Table 39. Differences between late subjective and objective results of stage II injuries in Magnusson's material and the present material

Components	Magnusson's material (118 patients)	Present material (38 patients)
Subjective results		
Discomfort		
Constant	11 (9.3 %)	—
Intermittent	24 (20.4 %)	7 (18.9 %)
Objective results		
Swelling & edema	17 (14.4 %)	9 (23.7 %) (malleolar size + ≥ 1 cm)
Tenderness ATFL	16 (13.6 %)	2 (5.3 %)
Atrophy of the calf (≥ 1 cm)	4 (3.4 %)	7 (18.9 %)
Pes plano-valgus	10 (8.5 %)	—
Pes transverso-planus	—	1 (2.6 %)

Table 40 Differences between late subjective and objective results of stage III injuries in Magnusson's material and the present material

Components	Magnusson's material (29 patients)	Present material (7 patients)
Subjective results		
Discomfort		
Constant	4 (13.8 %)	1 (14.3 %)
Intermittent	9 (31.0 %)	1 (14.3 %)
Objective results		
Swelling & edema	7 (24.1 %)	2 (28.6 %) (malleolar size + ≥ 1 cm)
Atrophy of the calf (≥ 1 cm)	3 (10.3 %)	1 (14.3 %)
Pes plano-valgus	3 (10.3 %)	—

Table 41 Differences between late subjective and objective results of stage IV injuries in Magnusson's material and the present material

Components	*Magnusson's material* (64 patients)	*Present material* (55 patients)
Subjective results		
Discomfort		
Constant	7 (10.9 %)	2 (3.6 %)
Intermittent	15 (23.4 %)	17 (30.9 %)
Objective results		
Swelling & edema	25 (39.1 %)	37 (67.2 %) (malleolar size + ≥ 1 cm)
Atrophy of the calf (≥ 1 cm)	7 (10.9 %)	14 (25.5 %)
Pes plano-valgus	9 (14.1 %)	—
Pes transverso planus	—	4 (7.3 %)

to the classification used by Magnusson and therefore a real comparison can be made The Tables 39, 40 and 41 show the differences between the subjective and the objective results of stage II, III, and IV injuries in Magnusson's follow up material and in the present follow up material Table 42 gives a collation of the differences involving the whole materials From the table it is clear that in Magnusson's material there are more patients with *constant discomfort* from their ankle injury than in the

Table 4? Differences between late subjective [illegible] of stage II, III and IV injuries in Ma[illegible] material [illegible]

Components	Magnusson's material (211 patients)	[illegible]
Subjective results		
Discomfort		
Constant	22 (10.4 %)	[illegible]
Intermittent	48 (22.7 %)	[illegible]
Objective results		
Swelling & edema	49 (23.2 %)	[illegible]
Atrophy of the calf (≥1 cm)	14 (6.6 %)	[illegible]
Pes plano-valgus	22 (10.4 %)	—
Pes transverso-planus	—	5 (15.0 %)
Roentgenological results		
Pseudarthrosis in the ATTu	54 (25.6 %)	—
Contour changes in the ATTu	103 (48.8 %)	10 [illegible]
Pseudarthrosis of the medial malleolar fracture	5/62 (8.1 %)	—
Displacement of posterior tibial fragment	20/73 (27.4 %)	[illegible]

present material. The difference is statistically almost s[illegible] late objective results the table shows that atrophy of the ca[illegible] to differences in the length of time of immobilization in pl[illegible] more common in the present material than in Magnusson's [illegible] difference is statistically highly significant. There is on th[illegible] Magnusson's material unilateral pes plano-valgus in such a [illegible] that the difference between the two materials is statis[illegible] ficant.

2. *Late roentgenological results*

Nor does Magnusson, when discussing the roentgenolog[illegible] detailed classification of his patients. There is accordi[illegible] no classification of good or poor results. There are rath[illegible] for instance, the displacements of the fracture fragmen[illegible] cases of unimalleolar fractures. Magnusson writes that [illegible] fibular fracture healed without marked dislocation. Chang[illegible]

were demonstrated in 82 cases (69 5 %) of which 27 were pseudarthroses and 55 contour-changes

The same opinion about the healing of the fibular fracture that was applicable to the unimalleolar fractures' was also applicable to the 29 cases of unimalleolar fractures with fracture of the posterior tibial margin' *Changes in the ATTu were demonstrated in 23 cases (79 3 %) of* which 7 were pseudarthroses and 16 contour-changes The posterior fragments appeared in 2 types partly shell shaped fragments which were not considered to be intra articular and partly large fragments involving the tibial articular surface 7 fragments belonged to the former group and the rest, 22 fragments to the latter group Among these last mentioned fragments 14 showed no displacement 3 an irregularity in the articular surface, and 5 a proximal displacement *amounting to 2 mm*

In 20 cases of bimalleolar fractures , the fibular fracture had healed without very great dislocation All the cases had injuries to the ATTu, consisting of 10 pseudarthroses and 10 contour changes 5 medial malleolar *fragments healed with displacement and 1 pseudarthrosis in the medial* malleolus was registered

In 33 cases of bimalleolar fractures with fracture of the posterior tibial margin *the fibular fracture had healed without any perceptible dislocation* 24 cases (72 7 %) had injuries to the anterior tibiofibular ligament consisting of 6 pseudarthroses and 18 contour changes No less than 31 of the 33 posterior fragments were intra articular 12 fragments were found to be displaced at the follow up examination 4 of them had not primarily been repositioned and 8 had been displaced during the time of treatment 3 instances of pseudarthrosis in the medial malleolus were registered, and *in 3 instances the medial malleolar fragment had healed with displacement.*

Of the 11 fractures with luxation of the ankle joint 8 had injuries to the ATTu 4 of them were pseudarthroses and 4 contour changes 1 pseudarthrosis in the medial malleolus was registered and 1 medial malleolar fracture healed with displacement In 2 cases the medial injury consisted of rupture of the deltoid ligament All the 11 luxation injuries had a *posterior fragment 3 fragments showed step formation at the follow up examination*

About the 64 stage IV injuries in Magnussons s follow up material it can summarily be said that 20 pseudarthroses could be demonstrated in the ATTu (31 3 %), that the fibular fractures healed without any great displacement that 9 medial malleolar fractures healed with displacement (14 5 %) that 5 pseudarthroses in the medial malleolus (8 1 %) were *registered and that 15 posterior tibial fragments were found to be displaced (34 1 %)*

From what is said above we conclude that a comparison between the roentgenological results in Magnusson's [illegible] material and the present [illegible] material is to a certain degree possible. There is in Magnusson's material a relatively high frequency of pseudarthroses in the MTh (20.6%) and the medial malleolus (8.1%) (see Table 42), whereas in the present material no pseudarthroses in the MTu or the medial malleolus could be recorded, certainly owing to the exact and stable immobilization enabled by the operative method used.

3 *Frequency of arthrosis deformans*

The frequency of arthrosis deformans in Magnusson's material can be studied in Table 43, where a comparison with the frequency of arthrosis deformans in the present material is also made. In this table it can be seen that Magnusson among his stage II injuries had a frequency of arthrosis deformans amounting to 29.7 per cent compared to 2.6 per cent in the present material. The difference is statistically significant. In stage III the corresponding figures are 62.1 per cent and 14.3 per cent respectively. The difference is statistically almost significant. In stage IV the figures are 79.2

Table 43. Differences between frequency of arthrosis deformans of stage II, III, IV and IV LUX injuries in Magnusson's material and the present material

Stage	Frequency of arthrosis deformans	
	Magnusson's material	Present material
II	35/118 (29.7 %)	1/38 (2.6 %)
III	18/29 (62.1 %)	1 [illegible] (14.3 %)
IV	42/53 ([illegible]9.2 %)	8/34 ([illegible]3.5 %)
IV LUX	9/11 (81.8 %)	13/21 (61.9 %)
Total	101/211 (49.3 %)	23/100 (23.0 %)

Table 44. Differences between degree distribution of arthrosis deformans in Magnusson's material and the present material

Degree of arthrosis deformans	Magnusson's material	Present material
(+)	85 (81.7 %)	13 (56.6 %)
+	15 (14.4 %)	8 (34.8 %)
++	4 (3.9 %)	1 (4.3 %)
+++	—	1 (4.3 %)
Total	104 (100.0 %)	23 (100.0 %)

per cent and 23 5 per cent, respectively The difference is statistically highly significant In stage IV, LUX the percentage difference, 19 9 per cent, is not statistically significant As a total, there is in Magnusson s material a frequency of arthrosis deformans amounting to 49 3 per cent compared to 23 0 per cent in the present material The difference is statistically highly significant Table 44 shows the distribution of arthrosis deformans with regard to the degree of severity in Magnusson s material and the present material There is in Magnusson s material a lower degree of severity The percentage difference for the mild forms, i e degree (+) and degree +, is statistically almost significant

XXXIV *Discussion*

To make a comparison between the results of conservative and operative treatment of ankle injuries is often very difficult In this work the author has tried to compare the late results of a material of operatively treated supination-outward rotation injuries with those of Magnusson s material of conservatively treated similar injuries Both materials derive from the same hospital and consequently from the same reception area The interval between the materials amounts to more than twenty years It is of great importance that there is no form of selection in the two materials Thus one has consistently used conservative and operative treatment of the ankle injuries

The comparison is however rendered difficult by the fact that the clinical as well as the roentgenological results have not been classified in an equivalent way, as the author in his material, contrary to Magnusson, has made a detailed classification of the results of treatment Nor are the materials quite comparable with regard to the sex age and stage distribution of the patients, which to a high degree can influence, for instance, the frequency of arthrosis deformans Magnusson has an even sex distribution in his material whereas the women are predominant in the present material which circumstance, according to experience, should involve an apparent disadvantage to the present material with regard to the results of treatment as well as the frequency of arthrosis deformans The mean age in the present material is higher than that in Magnusson s material, but the difference about 4 years is perhaps not so great as to affect the results to any high degree The materials differ very markedly with regard to the stage distribution Magnusson has a predominance of stage II injuries in his material, while stage IV injuries predominate in the present material, which circumstance involves a clear disadvantage to the latter material

Magnusson has a certain over representation of stage II injuries (unimal leolar fractures) at the expense of the stage IV injuries because he has divided up his material on a roentgenological basis on account of which ruptures of the deltoid ligament have happened to be unregistered He has however observed this as at the follow up examination of the stage II injuries he found 13 cases with roentgenological changes indicating that rupture of the deltoid ligament must have occurred primarily He also found 6 cases in which injury to the posterior tibial process must have occurred primarily These circumstances consequently prove that the clini cal result of the stage II injuries has been erroneously worse and the fre quency of arthrosis deformans erroneously higher If one makes a re-cal culation taking Magnusson s above mentioned follow up observations into consideration the frequency of arthrosis deformans for the stage II injuries can be reduced to about 18 per cent while it will correspondingly increase for the stage IV injuries to about 83 per cent This re-calculation will not affect the significant differences between the two materials to any high degree

The times of immobilization in plaster differ obviously in the two mate rials and are in Magnusson s material rather short especially for the stage II injuries Magnusson has also stated them to be insufficient It is diffi cult to decide what effect the difference in the mean time of immobiliza tion about 3 weeks has had on the result of treatment and on the fre quency of arthrosis deformans in the two materials As far as the present material is concerned the immobilization times have probably been un necessarily long which can be confirmed by the fact that a successive re duction of them has not involved any disadvantage to the results of treat ment

If a comparison between the results of treatment in Magnusson s material and the present material is made one will on several points find percentage differences speaking in favour of the latter material From a statistical point of view there are in the present follow up material fewer patients with constant subjective symptoms from the injured ankle and considerably lower frequency of arthrosis deformans in all the stages with the exception of the luxation injuries These differences are much the more remarkable as the present material is burdened by a predominance of female patients a higher mean age among the patients and a predominance of severe in juries The great difference in the frequency of arthrosis deformans could reasonably be due to the fact that the injuries in the present material have been treated according to an operative method which has allowed good and stable joint reconstruction especially by the use of the syndes mosis staple Of great interest here is the correlation between defectively healed ATFL-ruptures and arthrosis deformans which has been asserted

by Magnusson In the present material in which the ATFL ruptures have been carefully reconstructed, no pseudarthrosis in the ATTu could be registered, which circumstance, according to the above mentioned hypothesis might explain the decreased frequency of arthrosis deformans The fact that arthrosis deformans in spite of this ligamentous reconstruction, occurs in a frequency of about 20 per cent, must, I suppose, when discussing the causes of arthrosis deformans, involve the necessity of taking into due consideration also the other injury components and the reconstruction of them

Even if the follow up material because of its composition from a statistical point of view is representative of the total material, this does not necessarily involve that its results of treatment are applicable also to the last mentioned material Though the results of treatment of the follow up material must be considered very good, the late results may, however, be expected to be still better for those patients belonging to the latter half of the material In addition to clinical observations made, there are several reasons speaking for the truth of such an assertion Most of the results of the follow up material consequently pertain to patients operated on during a period when the operative method was being devised, and the surgeons had not obtained sufficient experience for the operations Nor was the syndesmosis staple in the beginning used at the reconstruction of the lateral injury components but it gradually found consistent use whereby better results of reconstruction could be achieved As has earlier been mentioned, also the primary clinical and roentgenological results have successively been better As regards the primary clinical results in those patients operated on in the years 1958—1961 and 1962—1965 respectively the number of medium and poor results (see Table 14) amounted to 13 of 132 (9 8 %) and 14 of 285 (4 9 %) cases, respectively implying a percentage predominance of inferior results of treatment in the first mentioned group of patients From a roentgenological point of view there are also percentage differences in respect to the primary result Thus the patients in the follow up material had anatomical results in 63 0 per cent good results in 17 0 per cent and poor results in 20 0 per cent, while the corresponding figures for the 306 stage II III and IV injuries not followed up, were 69 9 per cent 14 7 per cent and 15 4 per cent The percentage differences are however not statistically significant Also the sick leave has successively decreased which indicates that the results of treatment have gradually become better

In order to ascertain the late results of the operative treatment of the supination-outward rotation injuries in this material those patients operated on in the years 1958—1961 (132 patients) were subjected to a follow up examination with an observation time of at least 5 years 111 of them (84.1 %) could be judged with respect to their subjective symptoms and 100 (75.8 %) could be subjected to a complete clinical and roentgenological follow up examination From a statistical point of view the follow up material with respect to sex age and stage distribution proved to be representative of all those 132 patients operated on in the years 1958—1961 as well as the 417 patients of the total material

With regard to the subjective result of treatment the patients have been divided up into 3 groups namely "good" "medium" and "poor" results 88 per cent of the patients had "good" 6 per cent "medium" and 6 per cent "poor" results The best results were obtained in the stage II injuries 94.7 per cent of which had "good" results. The worst results were obtained in the stage IV injuries of which 83.6 per cent however had "good" results.

Also with respect to the objective result of treatment the patients have been divided up into the corresponding 3 groups 59 per cent of the patients had "good" 38 per cent "medium" and only 3 per cent "poor" results. Here also the best results were obtained in stage II and the worst in stage IV

During the observation time the clinical results of treatment have changed to a slight degree only which means that the primary clinical results can give good information about the future function of the injured ankle of the patients

From a roentgenological point of view the patients have been divided up into 3 groups namely "anatomical" "good" and "poor" results With regard to medial malleolar fractures and posterior tibial fractures the classification has been stricter than that one used for the primary results of reduction because, in a healed ankle injury it is often difficult to establish and measure slight fragment displacements and displacements in posterior tibial fractures are successively levelled and thereby not very conspicuous 68 per cent of the patients had "anatomical" 19 per cent "good" and 13 per cent "poor" results. No pseudarthrosis was registered

There has been a very good accordance between the subjective the objective and the roentgenological results Women had generally worse results of treatment than men

The post traumatic arthrosis deformans of the ankle is discussed with respect to etiology beginning and correlation to the patients sex and age

and the severity of the ankle injury Arthrosis deformans in the present material was classified according to Magnusson It was registered in a total of 23 patients of whom 17 were women and 6 men, implying a predominance of the first mentioned Only 2 of the patients both women had severe changes 21 of the patients were more than 40 years old, and the mean age of the women was somewhat higher than that of the men The frequency of arthrosis deformans in stage II was 2 6 per cent, in stage III 14 3 per cent, in stage IV 23 5 per cent, and in stage IV, LUX 61 9 per cent Arthrosis deformans could be demonstrated in only 15 out of 88 patients (17 0 %) with 'good subjective results, in 3 out of 6 patients (50 0 %) with medium subjective results and in 5 out of 6 patients (83 3 %) with poor subjective results The figures imply that there is a significant correlation between subjective symptoms and arthrosis deformans Arthrosis deformans could further be demonstrated in only 9 out of 68 patients (13 2 %) with anatomical roentgenological results in 7 out of 19 patients (36 8 %) with good roentgenological results and in 7 out of 13 (53 8 %) with poor roentgenological results The figures imply that there is a significant correlation between the roentgenological results of reconstruction and arthrosis deformans A significant correlation was also established between arthrosis deformans and posterior tibial fractures, healed with displacement At a comparison between displaced and nondisplaced posterior tibial fragments, one could find that with regard to percentage large fragments were more often accompanied by arthrosis deformans than were small ones

Of the 100 follow up patients about 50 per cent had happened to be operated on with and about 50 per cent without the use of the syndesmosis staple An investigation showed that patients in stage IV, operated on with syndesmosis staple, had a significantly higher frequency of anatomical reconstructions and with regard to percentage a lower frequency of arthrosis deformans than patients in this stage, operated on without syndesmosis staple

The results of treatment in the present follow up material have been compared with the results of treatment obtained by Magnusson (1944) in a follow up material of conservatively treated supination outward rotation fractures The comparison was difficult as the clinical as well as the roentgenological results were not equivalently classified The materials are not comparable either as the sex age and stage distribution of the patients is so different as to involve a clear disadvantage to the present material Besides there are also differences with respect to the length of the times of immobilization in plaster in the two materials From a statistical point of view there are in comparison with Magnusson s material, in the present follow up material fewer patients with constant subjective symptoms from

the injured ankle and a considerably reduced frequency of arthrosis deformans in all the stages with the exception of the luxation injuries The causes of the reduced frequency of arthrosis deformans are discussed at which the author emphasizes that this reduction must depend on the operative method used which especially thanks to the syndesmosis staple, enables good and stable joint reconstruction The results of treatment are valued at which the author emphasizes that they can probably be expected to be still better for those patients belonging to the latter half of the total material

XXXVI General summary and conclusions

Part I deals with the clinical and roentgenological diagnosis of supination outward rotation injuries in adults and the joint changes registered at operative exploration of these injuries For summary see page 62

Part II deals with the operative method used in the reconstruction of supination-outward rotation injuries and the primary clinical and roentgenological results of this treatment For summary see page 97

Part III deals with the late clinical and roentgenological results of treatment in most of those patients operated on in the years 1958—1961 The results are compared with the late results of conservative treatment (Magnusson 1944) For summary see page 137

With the support of operative observations made and results of treatment obtained in this material and experiences reported on in other investigations the following summing up can be made as to the operative indications for supination-outward rotation injuries of the ankle

Stage I injuries Strong indication for operation at the occurrence of a roentgenologically visualized bone fragment originating in the ATTu or the lateral malleolus With conservative treatment there is probably a great risk of pseudarthrosis formation resulting in symptoms of insufficiency from the anterior part of the tibiofibular syndesmosis (Magnusson 1944) A rupture located in the ligamentous substance should have a good prognosis with conservative treatment, provided the injury is treated with immobilization in plaster for at least 6 weeks The advantage of an operation also of this type of ligamentous injury is that one obtains a reliable healing of the ligament Clayton 1959 and that the length of the immobilization time can be essentially reduced, especially if the ligamentous suture is stabilized by a syndesmosis staple

Stage II injuries The ATFL rupture and the distal oblique fibular fracture should, with regard to treatment be considered a unit Strong indication for operation at the occurrence of a roentgenologically visualized bone fragment belonging to the ATFL and/or displacement of the distal fibular fragment in lateral, dorsal, or proximal direction, or in outward rotation An oblique fracture without displacement and combined with a ligamentous rupture without a visible bone fragment would seem to have a good prognosis with conservative treatment, provided the immobilization in plaster is of sufficiently long duration The advantage of operation also in these cases is probably in conformity with the above that the healing of the ligament is ensured and besides, that secondary fragment displacement is prevented By operation also laterally situated free cartilage or bone fragments can be established and removed Also the time of immobilization can probably be reduced if the injury is operatively treated

Stage III injuries The same indications as those for stage II injuries should be applicable Posterior tibial fragments in size involving more than one fourth of the articular surface and showing proximal displacement should be subjected to osteosynthesis, while small bone fragments do not generally require special operative measures

Stage IV injuries The same indications as those for stage II injuries should be applicable to the lateral injury component and the same indications as those for stage III injuries to the posterior tibial fragments Strong indication for operation on the medial side in all those cases which, in the roentgenograms show displaced medial malleolar fracture and in all those cases which show signs of rupture of the deltoid ligament with either marked clinical symptoms or in the roentgenograms, a pathologically large distance between the medial malleolus and the talus If there is any uncertainty as to the occurrence of a ligamentous rupture, an operative exploration should be performed With conservative treatment the medial malleolar fracture involves the risk of pseudarthrosis formation as soft parts are as a rule interpositioned in it Operation also enables the establishment and the removal of medially situated free cartilage or bone fragments and besides a reduction of the immobilization time

The luxation injuries will probably always require operative treatment Even if at conservative as well as operative treatment, the frequency of arthrosis deformans is high possibly due to the occurrence of mechanical as well as nutritive injuries to the joint cartilage it can be reduced by exact joint reconstruction

With regard to the stable fixation of the injuries in this material enabled by the operative method used the times of immobilization in plaster might be further reduced The patients would thereby be able to start their movement exercise earlier, which would probably reduce the frequency of

atrophy of the calf and remaining restriction of the range of motion in the ankle. This procedure might also be supposed to lead to some reduction of the time of treatment and therefore accelerate the patient's return to work. The author does not consider a complete elimination of the treatment in plaster to be advisable. In the postoperative period the plaster is probably valuable for the patient as it can reduce pain and promote the normal healing of the wound. Also later on during the treatment the plaster would seem to be of value for the healing of injuries to the joint capsule and of such sutured ligamentous ruptures in which the suture, contrary to stage I injuries, cannot be subjected to any stabilizing procedure.

Attempts aiming at further reduction of the time of immobilization in plaster have been started.

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